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FINAL REPORT ON THE AWS SFERICS EVALUATION PROJECT (1951)

AUGUST 1954

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AIR WEATHER SERVICE
MILITARY AIR TRANSPORT SERVICE
UNITED STATES AIR FORCE
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FOREWORD

1. Purpose: This report is published to inform forecasters and other personnel concerned with the development and operational use of sferics, of the full results of an AWS project to evaluate the meteorological worth of sferics. The detailed observations and charts presented will facilitate interested personnel in judging the validity of the conclusions drawn, which have already been published in AWS Technical Report 105-87 and AWS Manual 105-38.

2. Scope: The report covers historical background and planning of the Project, preliminary phases of the investigation, development of techniques for reducing and analyzing the observations, discussion of the analyzed data, the correlations found, errors in the observations, conclusions, and Project costs and personnel.

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FINAL REPORT ON THE AWS SFERICS EVALUATION PROJECT (1951)

PART I. - GENERAL

1. Introduction

Electromagnetic disturbances in the atmosphere or atmospherics ("sferics") have been detected, analyzed, and attributed to various causal phenomena by electronics engineers and meteorologists since 1895. Published literature on the sferics problem abounds. A historical summary of much of this literature (Weather Service Bulletin No. 1, 1951, pp. 48-60 [4]) was prepared as the first report of the Sferics Evaluation Project (see below).

The electronics engineers have been concerned with sferics primarily in regard to noise level and undesired triggering effects; in other words, sferics are considered to be operational detriments in this field.

The meteorologists, on the other hand, have been interested in the locating of sferics sources by some method, such as triangulation of bearings derived from a network of radio direction-finding stations. It has been hypothesized that these sferics fixes are synonymous with the locations of thunderstorms, which, in turn, may be associated with cyclogenesis, air-mass instability, warm-frontal overrunning, or pre-cold-front squall-lines. The value of such data is particularly apparent when derived from regions where the normal synoptic data are sparse, such as ocean areas.

Although the meteorological interest in the sferics-thunderstorm association and in the synoptic utilization of sferics data has been keen in some quarters, proof of this association and its utilization has not been demonstrably conclusive to gain the support of the majority of the meteorologists. In other words, much doubt accompanied the claims of the sferics enthusiasts. Occasionally sferics fixes seemed to be misleading; i.e., they were located where the synoptic patterns were not indicative of strong convective activity, such as the centers of high-pressure systems. A myriad of other causes, both meteorological and non-meteorological in nature, was suggested, but none was given any convincing proof. A problem existed regarding the origin of sferics. Thus, confidence was low in the minds of most meteorologists regarding the acceptance of sferics data as being indicative of thunderstorm activity, and consequently regarding the utilization of these data.

2. Activities of Sferics Evaluation Project

Primarily through the efforts of Dr. Sverre Petterssen, who sought to throw some light upon the sferics problem, the Air Weather Service initiated a Sferics Evaluation Project during the latter part of 1950. Actual work was begun on 1 February 1951, with the assignment of a project officer. The facilities of the Air Weather Service Caribbean Sferics Net were made available to the project. This net consists of stations at Ramey Air Force Base, Puerto Rico; Kindley Air Force Base, Bermuda; MacDill Air Force Base, Florida; and Robins Air Force Base, Georgia. For the purposes of the evaluation project, a fifth station was activated at Fort Monmouth, New Jersey. For a more detailed account of the sferics equipment (AN/GRD-1A) and allied photographic instrumentation, the reader is referred to War Department Technical Manuals 11-2693 and 11-2338, respectively. Figure 1, however, is a picture of this equipment as it is installed at the Net Control Station (Robins AFB). Figure 2 shows the Sferics Project and Net Control buildings at Robins; the box-like structures, on the building at the left, house the loop antennas associated with the AN/GRD-1A. Figure 3 shows the radio communications equipment at the Net Control Station for use in the mutual exchange of directional characteristics and timing of sferics flashes as photographed on the cathode ray oscilloscope. A reference (4) is cited for a more detailed account of the normal operational procedures of the Caribbean Net.

With the exception of the Project Director (Maj. C. E. Jensen), the personnel assigned to the Sferics Evaluation Project and their respective tours of duty with the project are tabulated in Appendix I. The results of the project, herewith reported, represent an outstanding effort on the part of these personnel, both individually and collectively. Special words of appreciation are due Captain James W. Green, Captain Mack Siler, Jr., S/Sgt. Walter N. Leneau, and A/1C James C. Kidd. Captain Green exhibited inspired initiative and courage during the initial phases of the study, and contributed substantially to the success of the project. Captain Siler replaced Captain Green as assistant project director in August 1951 and continued the high spirit of vigorous pursuit of the project goal. Sergeants Leneau and Kidd were outstanding among the airmen in developing team spirit and in displaying a sense of duty well above that normally realized.

3. Statement of Problem

The purpose of the project was to determine the meteorological significance of sferics data. This general purpose was divided into two specific problems: (1) whether or not all sferics fixes have their origin in lightning flashes, and (2) if all sferics fixes have their origin in lightning flashes, how may the

meteorologist use such data? The second problem was, of course, contingent upon results gained in solving the first.

PART II

PRELIMINARY INVESTIGATIONS

1. Introduction

In attacking the problem to determine the meteorological significance of sferics data, it was felt that some knowledge of the climatology of sferics fixes and of the scope of the Caribbean net was necessary. Climatology and scope go hand in hand, in this instance, and monthly sferics distribution charts were prepared as a continuing program starting with June 1950.

It was also deemed desirable to compare the monthly sferics distribution charts with normal thunderstorm distributions in order to establish at least a general relationship between sferics fixes and thunderstorms. This was done for an eleven-month period beginning with June 1950.

In addition, the effects of ionospheric and magnetic storm activity on sferics propagation were investigated as possible sources of interference and error.

2. Monthly Sferics Distribution Charts

For the purpose of gaining knowledge relative to the climatology of sferics and to the scope of the Caribbean net, monthly distribution charts of sferics fixes were prepared for the months June 1950 through May 1952 and these charts are included as Figures 4 through 27. They encompass an area enclosed by the meridians 40°W to 105° W and the parallels 5°N to 50°N. Utilizing a grid system composed of basic squares, $2\frac{1}{2}^{\circ}$ of latitude by 5° of longitude, the monthly total of fixes falling within each square was noted and isopleths drawn. The data used were derived from the normal runs of the original four-station Caribbean net. Normal operation during the period investigated consisted of four-minute runs every six hours. Fixes were obtained utilizing a 120-flash sampling technique (4) for each four-minute run.

An examination of the monthly distribution charts for the year, June 1950 through May 1951, shows a gradual diminishing of the centers of sferics activity over the eastern United States and an

intensification of activity over northern South America during the period Junethrough November. Relative stagnation of the centers of sferics action occurs from December through February, and a gradual northward displacement of these centers takes place during the period March through May.

Much the same pattern changes take place for the year, June 1951 through May 1952. It is noteworthy, however, that the sferics activity for February and May of 1952 was considerably greater over the Eastern United States and Atlantic than for the corresponding months of 1951. The other months compare reasonably well from year to year.

3. Association of Sferics and Thunderstorm Patterns

Figures 28 through 38 show the association between the monthly (June 1950 - April 1951) sferics distribution patterns and the monthly average number of thunderstorm days, the latter after Alexander from his 40-year record (1904 - 1943) (1). Although one year may vary considerably from the next and thus it is not very significant to correlate a specific year with a 40-year normal, Figures 28 through 38 are included to show the general area association between sferics fixes and thunderstorm activity. This same type of study had been accomplished by other investigators in other perts of the world with similar results. It was felt necessary, however, to perform this study as a first step in determining the origin of sferics fixes. It should be noted that the actual magnitudes assigned the isopleths of fix frequency may not be converted in any convenient manner in order to be compared directly with the isopleth values of frequency of thunderstorm days. The two patterns for each month show general correspondence, although the significance of this is limited, as stated above. This association was made using only that portion of the United States east of the 105th meridian. Thunderstorm data over the ocean areas are not very reliable. Data after Brooks, however, were used for general area association and the patterns for each month showed similar correspondence.

4. Weighted Monthly Totals of Sferics Fixes

Supplemental information is included as Figure 39 which is a plot of the weighted monthly totals of sferics fixes for the period June 1950 through March 1951. Daily averages for each month were multiplied by a factor of 30, so that a more realistic monthly fluctuation in the number of fixes could be presented. The graph shows a maximum number of fixes for July (6550) and a minimum for January (5350), although fluctuations from month to month do not appear to be systematic.

5. Effects of Ionospheric and Magnetic Storm Activity on Sferics Propagation

Sudden ionospheric disturbances (SID), periods of abnormally great absorption, are characterized by simultaneous high frequency communication fadeouts over the daylight hemisphere of the earth when such communication is dependent upon sky-wave propagation. These are primarily sky-wave absorption phenomena and thus do not affect the ground wave propagation of the very long waves (10 kc) wherein the maximum power of sferics discharges are concentrated and with which we are primarily concerned. Ionospheric reflections associated with sferics have been observed, however, by Kessler and others (6). These returns were observed to be well-defined only at night, and then only for approximately 2.7% of the time. When these ionospheric returns occur, they occasionally distort the appearance of the ground pulse as detected by the AN/GRD-1A into an elliptical pattern; the interference being caused by a phase difference between the return and the ground pulse, when the time interval separating the two has been reduced by the relative slowing down of the ground pulse.

Magnetic storms are defined as severe electromagnetic disturbances. Little is known about the effects of such storms on the propagation of low frequencies of the order of 10 kilocycles per second to which the sferics equipment is tuned. Magnetic storms (above-normal fluctuations in the magnetic field of the earth) last from several hours to several days and are very often characterized by a sudden commencement which is simultaneous all over the earth to within a few seconds. Magnetic storms correlate positively with sunspots, with the most frequent and violent storms occurring during and slightly after the maximum of the sunspot cycle. The most satisfactory theory attributes magnetic storm activity to the effects of charged corpuscular radiation from the sun. Bursts of corpuscles, emanating from the active regions of the sun which are usually associated with active sunspot groups, are deflected by the magnetic field of the earth, producing ring currents around the earth, and aurora. The appearance of auroral displays in lower latitudes produces high absorption due to the ionization at low levels. This low level absorption effect is perhaps the most important deterrent to the propagation of the very long waves. An attempt was made to determine the extent of this effect by comparing the indices of magnetic storm activity (K-indices) with the monthly average percentage of instances when two or less stations recorded bearings corresponding to designated time groups called by the controlling station. It should be noted that at least three-station participation is necessary for the production of a reliable fix. K-index figures were obtained from daily reports

of the Cheltenham Magnetic Observatory.

Figure 40 is a plot of the monthly average percentage of instances when two or less stations recorded bearings, and the monthly average K-index for the months, June 1950 through March, 1951. Points plotted correspond to the four daily runs taken at 0000Z, 0600Z, 1200Z, and 1800Z. With minor exceptions the two curves are generally 180° out of phase indicating at first glance that the greater the magnetic storm activity the smaller the number of instances when a particular flash will not be detected by at least three stations. In other words, it would appear that magnetic storm activity increases the intensity of the original discharges or aids the propagation of these pulses, or both. In support of the latter observation, investigators at the Central Radio Propagation Laboratory of the Bureau of Standards concluded from a study of the propagation of 18 kilocycles per second pulses that magnetic storms tend to aid the transmission of such low frequencies although the overall effect is very small (2). In this connection, however, it should be noted that transmission characteristics may vary appreciably for frequencies separated by only a few kilocycles.

In an attempt to determine the effects of magnetic storm activity on the bearings of the discharge pulses, Figure 41 was prepared showing graphs of the monthly average percentage of fixes obtained based upon those possible (detection from at least three stations), and the monthly average "K" index for the months June 1950 through March 1951. The abscissas are the same as in Figure 40. The two curves appear also to be generally 180° out of phase with respect to each other indicating at first glance that the greater the magnetic storm activity the smaller the number of fixes. From this analysis, it may be concluded that magnetic storm activity influences the directional bearings of sferics to some extent.

Figures 42 and 43 are composite graphs representing by smoothed curves the data derived from Figures 40 and 41, respectively. Data for the four daily runs have been averaged for each month. Correlation coefficients of -.212 and -.344, respectively were determined. These correlation coefficients indicate only that a tendency toward an inverse relationship exists. The conclusion that may be drawn, therefore, is that the overall effect of magnetic storm activity on the propagation characteristics of sferics is small.

6. Diurnal Variation of Sferics Fixes

Supplemental information is included as Figure 44 which depicts the diurnal variation of sferics fixes for the period June 1950 through March 1951 utilizing mean data for each of the four daily run times. The curve exhibits a maximum at 0000Z and a minimum at 1200Z. It should be noted that this graph does not reflect the

frequency of sferics flashes since 120 flashes were selected at random for each run and fixes derived from this equal sampling. The graph does suggest, however, that either the intensity of sferics activity is a minimum at 1200Z resulting in less cases of at least three-station participation, or the propagation of sferics is adversely affected to the greatest extent at this time of day. Reference is made to Figure 40 and to conclusions drawn therefrom. It is noted that the overall diurnal variation in magnetic storm activity follows closely the pattern of the curve under discussion exhibiting also a distinct minimum at 1200Z. The conclusions suggested by Figure 44 may, therefore, offer further substantiation of those derived from Figure 40.

PART III

DIRECT ASSOCIATION OF SFERICS AND THUNDERSTORMS

(Complete Flash Analysis)

1. Introduction

The difficulty with studies in the past which attempted to relate sferics and thunderstorms has been the scarcity of meteorological data for association purposes. Normal distribution associations were made, such as in Part II 3, above, but these are not considered conclusive in establishing the origin of sferics fixes. To solve the first problem, therefore, it was necessary to find some means of obtaining special observations of thunderstorm activity in synchronism with the operation of the sferics net.

2. Establishment of Thunderstorm Reporting Network

For this special network of observers, the cooperation of the U. S. Weather Bureau and the American Telephone and Telegraph Company was solicited and gained. Without this voluntary support, the evaluation program would not have been successful. Approximately 8500 Weather Bureau Cooperative Observers, 3000 Bell System Offices, and all U. S. Weather Bureau first order, CAA and AWS type A, C, D weather stations located in forty-one states east of the 105th meridian were organized into a special thunderstorm observing net. Figure 45 shows the distribution of these observers over the area concerned. This chart was prepared utilizing a grid system of 1/2° tessera ("squares"); as many as thirty-four observers were reported in a basic square, such as around the large cities. This same grid system was utilized in the final superposition of sferics fixes and reports of thunderstorms.

Each observer in this dense network was requested to complete a special thunderstorm data card, a sample of which is inclosed as Figure 46, daily during July 1951. As noted on the data card, the thunderstorm observations (audible thunder or the appearance of lightning) were to be made for a two-minute period every hour on the half-hour. Operation of the sferics net was synchronized with the time of these observations, utilizing the time signals of station WWV.

3. Analysis of Data

All film records collected during July 1951 and completed data cards were mailed to the project location at Robins Air Force Base. A special Sferics Film Viewer, Rapid Plotting, was designed and constructed at the Signal Corps Engineering Laboratory primarily as a time saving device in the analysis of the tremendous amount of film collected (approximately 37,200 feet of 35mm film at a camera speed of one inch per second). Figure 47 is a sample of the film record showing the WWV tone, flashes with directional characteristics, time counter, 1/10th and 1 second markers. Figure 48 is a picture of the special film viewer. It permits the simultaneous analysis of the film from the five participating stations. Sharp beams of light which may be rotated manually about each station circle by means of a gear mechanism are lined up in accordance with the azimuth of the flashes read on the film. When time groups are properly synchronized and the azimuthal light beams aligned, fixes are rapidly located.

The following runs were completely analyzed (every discernible flash) by the project and will be discussed in later sections of the report:

TIME	DATE
0730Z	6 July 1951
1330Z	6 July 1951
1530Z	6 July 1951
0630Z	7 July 1951
1430Z	7 July 1951
1130Z	9 July 1951
1330Z	11 July 1951
0030Z	20 July 1951
0630Z	20 July 1951
1830Z	20 July 1951

The selection of these ten runs from a possible 744 was based upon the following considerations listed in order of their importance:

(1) Five-station participation was mandatory.

(2) The film from each station had to display a clear WWV tone indicating correct time synchronism.

(3) The film from each station had to be readable. It was stipulated that the time markers (1/10 and 1 second) should be distinct and that the activity be light enough so as to remove all uncertainties from the reading of the time groups associated with specific flashes.

(4) Synoptic map-times were considered to be of some importance so as to permit synoptic associations of the same data used for the direct associations.

Because of the limitations (1), (2), and (3), above, it is estimated that only 5% of the 744 runs made during July could be considered usable for the purposes of this investigation. The majority of runs were disqualified because of too much "activity" appearing on the film, rendering the time-reading of individual flashes extremely uncertain. This condition can be readily alleviated by increasing the film speed. Failure to receive clear WWV time signals accounted for a substantial number of the discarded runs. This discrepancy is a propagation and local radio interference problem.

Since the radio direction-finding equipment is considered accurate to only ±2 and observer uncertainty in reading the azimuths of flashes is estimated as ±1 , a fix was plotted if the figure defined by at least three azimuths could be closed to a point by movement of each azimuth a certain amount up to a maximum of ±3 . In all error triangles up to a "maximum" triangle (one which can be just closed down to a point by rotating each azimuth through 3 degrees), the center of the inscribed circle (intersection point of bisectors of the angles) was used as the fix location. This point is a compromise between the "Steiner" point and the centroid. The former is defined as the point at which each side of the error triangle subtends 120°. The latter is the intersection of the medians. A comparison study of the accuracy of the "Steiner" point versus the centroid and the center of the inscribed circle was undertaken in the past (author unknown). The criterion used was: the smaller the magnitude of the sum of the angular deviation ($\Sigma\alpha$), the more probable the point. Three "maximum" triangles were investigated with the following results:

(1) Triangle I

S ("Steiner" point)	28.1
I (Center of Inscribed Circle)	32.4
C (Centroid)	56.5

(2) Triangle II

S	("Steiner" point)	26.0
I	(Center of Inscribed Circle)	39.7
C	(Centroid)	87.9

(3) Triangle III

S	("Steiner" point)	169.0
I	(Center of Inscribed Circle)	53.8
C	(Centroid)	305.7

The author concluded from the above comparison that "it is only in the exceptional case, such as where a station lies between two vertices of an error triangle (case III above) that the 'Steiner' point gives poor results, as determined by the criterion." The case not discussed by the author is the elongated error triangle where one angle is 120° or greater and the "Steiner" point is then the vertex of that angle. This type of error triangle results when the indicated bearings at two of the participating stations are almost parallel due to (1) the great distance between source and stations, (2) the orientation of the stations with respect to the source and (3) the baseline length. The uncertainty in locating a fix within such an elongated triangle will henceforth be referred to as the parallel beam uncertainty. For the sake of consistency and after an evaluation of the results of the comparison study mentioned above, the center of the inscribed circle was chosen as the fix location in all types of error triangles. In other cases of a quadrilateral or pentagon, the fix was placed at the intersection of the diagonals.

4. Discussion of Results

The grid system of 1/2° squares was used in the preparation of Figures 49 through 58. Squares containing X's represent sferics fixes, squares containing slanting lines represent thunderstorm reports, and completely filled in squares denote coincidence of fixes and reports. Some of these results were included in AWS Technical Report 105-87 [5]. It should be noted that the squares representing reports of thunderstorms and coincidence will appear only over portions of the United States where observers are physically located (see Figure 45). In this section, only fixes falling within this same area will be discussed. On the original work-charts, the number of fixes falling within a particular basic square was entered in the upper left hand corner, and the number of observers reporting thunderstorm activity was entered in the lower right hand corner

of each appropriate square. The former numbers reflect the frequency of flashes from a particular thunderstorm area and consequently the severity of that storm area. More will be said concerning this in Part IV. The latter numbers are a function of the density of observers, and thus only of passing interest. The two sets of numbers cannot be compared directly, since the observers were asked to report thunderstorm activity and not the number of individual flashes.

In the tabulation of the direct association results which follows, only the major areas of fixes and thunderstorms are listed. With the exception of the phenomenon of fixes "undershooting" the sources, the major areas of fixes and reports of thunderstorms over continental United States east of the 105th meridian are reasonably coincident. Further, no major area of reports remained undetected, nor did any major area of fixes remain unverified. The suggested reasons (to be discussed in detail in Part VIII) for the discrepancy termed "undershooting" are (1) the inherent instrumental errors and (2) the phenomenon of parallel beam uncertainty.

Thunderstorm activity not detected by the net was isolated or well-scattered. The suggested reasons for this limitation of the net are:

(1) The more active and more intense source regions "blank out" the film record of the isolated activity.

(2) The discharges from the scattered thunderstorms are perhaps not of sufficient strength or power to reach at least three stations of the net.

The fixes not reasonably associated (within 1 or 2^{o}) with reported thunderstorm activity were isolated or they comprised sparse clusters which "undershot" the sources appreciably. The average percentage of these scattered fixes versus total fixes is 6% for the ten runs analyzed. A substantial portion of the isolated fixes not verified was located in Florida where an unfortunate incident deprived the project of the services of the U. S. Weather Bureau volunteer cooperative observers. A shipment of 5000 thunderstorm data cards, which were to be distributed to approximately 170 cooperative observers in Florida by the U. S. Weather Bureau Section Director at Jacksonville, was inadvertently misplaced and never reached its destination. Reports from Florida would, therefore, only represent the efforts of AT&T offices and AWS, CAA, and U. S. Weather Bureau first-order stations. The combination of these is still meager in comparison with the number of observing stations that the cooperative observers would have furnished within the State of Florida, and consequently the chances for verification of the

fixes in this region were lessened considerably. Other reasons for the non-verification of fixes are suggested below:

(1) Errors in location of fixes due to parallel beam uncertainties and to inherent instrumental errors to be discussed in Part VIII.

(2) Called flashes not properly synchronized at other participating stations due either to a drift in the electro-mechanical timing device or to the density of activity on the film record.

The association of the major areas of thunderstorm activity with the major areas of fixes is tabulated below. The center of the sferics net mentioned in one of the column headings is defined as 30°N 73°W.

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TABULATION OF DIRECT ASSOCIATION RESULTS FOR JULY 1951

Association of Major Areas of Thunderstorm Activity with Major Areas of Fixes

Run	Reference	Approximate Center Location of Thunderstorm Area; Approximate Distance From Center of Net and Description of Area	Center Location of Major Area of Fixes with Respect to Center of Major Thunderstorm Area, and Description of Area	Remarks
060730Z	Fig. 49	40°N 95°W 1500 miles Dense band	Coincident Dense band	Area of fixes envelops thunderstorm area.
060730Z	Fig. 49	47°N 105°W 2500 miles cluster	200 miles S. E. cluster	Strong evidence of fixes "undershooting" sources.
061330Z	Fig. 50	39°N 95°W 1500 miles Dense band	Displaced eastward approx. ½° Dense band	Presents evidence of fixes "undershooting" sources.

TABULATION OF DIRECT ASSOCIATION RESULTS FOR JULY 1951

Association of Major Areas of Thunderstorm Activity with Major Areas of Fixes (Cont'd)

Run	Reference	Approximate Center Location of Thunderstorm Area; Approximate Distance From Center of Net and Description of Area	Center Location of Major Area of Fixes with Respect to Center of Major Thunderstorm Area, and Description of Area	Remarks
061530Z	Fig. 51	39°N 95°W 1500 miles Dense band	Displaced eastward approx. 1°; Dense band	Fairly strong evidence of fixes "undershooting" sources.
070630Z	Fig. 52	47°N 90°W 1500 miles Sparse band	Coincident Dense band	Area of fixes envelops thunderstorm area.
070630Z	Fig. 52	37°N 99°W 1700 miles Dense band	Coincident Sparse line	Although this area of thunderstorms appears larger than the preceding one, the distribution of sferics activity indicates the latter one to be more active.
071430Z	Fig. 53	45°N 86°W 1300 miles cluster	Displaced southward approx. 1°; cluster	Presents evidence of fixes "undershooting" sources.
091130Z	Fig. 54	39°N 89°W 1200 miles Dense band	Coincident Dense band	Fixes appear more concentrated than reports of thunderstorms.

TABULATION OF DIRECT ASSOCIATION RESULTS FOR JULY 1951

Association of Major Areas of Thunderstorm Activity with Major Areas of Fixes (Cont'd)

Run	Reference	Approximate Center Location of Thunderstorm Area; Approximate Distance From Center of Net and Description of Area	Center Location of Major Area of Fixes with Respect to Center of Major Thunderstorm Area, and Description of Area	Remarks
091130Z	Fig. 54	40°N 100°W 1900 miles Dense block	200 miles S.E. cluster	Strong evidence of fixes "undershooting" sources.
111330Z	Fig. 55	38°N 95°W 1500 miles Dense band	Displaced eastward approx. 1° Dense band	Presents evidence of fixes "undershooting" sources.
111330Z	Fig. 55	42°N 103°W 2100 miles cluster	250 miles S.E. cluster	Strong evidence of fixes "undershooting" sources.
200030Z	Fig. 56	Extensive band along eastern seaboard and Gulf Coast	Coincident	None
200030Z	Fig. 56	36°N 105°W 2200 miles cluster	Displaced eastward cluster	Strong evidence of fixes "undershooting" sources.
200630Z	Fig. 57	44°N 97°W 1700 miles Extensive band	Displaced slightly southeastward Extensive band	Evidence of fixes "undershooting" sources.

TABULATION OF DIRECT ASSOCIATION RESULTS FOR JULY 1951

Association of Major Areas of Thunderstorm Activity with Major Areas of Fixes (Cont'd)

Run	Reference	Approximate Center Location of Thunderstorm Area; Approximate Distance From Center of Net and Description of Area	Center Location of Major Area of Fixes with Respect to Center of Major Thunderstorm Area, and Description of Area	Remarks
201830Z	Fig. 58	Extensive line along Gulf Coast terminating in Florida	Coincident Extensive band	None
201830Z	Fig. 58	37°N 106°W 2300 miles cluster	Displaced eastward Extensive cluster	Major portion of source region is beyond edge of map--particularly strong evidence of fixes "undershooting" sources.

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The tabulation shows that, within a range of approximately 2000 miles from the center of the net, major areas of sferics are essentially coincident (evidence of slight "undershooting") with major areas of thunderstorm activity. Beyond that range, the fixes "undershoot" the sources to an appreciable extent, as a result of inherent instrumental errors and/or the parallel beam uncertainty.

Scattered isolated thunderstorm activity not detected by the net was negligible and insignificant in proportion to the activity represented by major thunderstorm areas.

Fixes not verified by thunderstorm activity amounted to approximately 6%. Except for a considerable number comprised in clusters which undershot the source regions, these fixes were scattered and negligible in comparison to the major concentrations of fixes.

The locations of scattered fixes should be eliminated from the transmitted sferics message, which should only reflect the occurrence of bands, clusters or lines of fixes. Proper corrections for parallel beam uncertainties and inherent instrumental errors should be applied to the locations of such areas when they occur at distances greater than 2000 miles from the center of the net, or the transmitted sferics message should only include data within the specified range of accuracy.

Figures 49 through 58, although only a small sampling of the available data, are believed to be representative of the capabilities and limitations of the Caribbean Sferics Net. The data show that the net can detect accurately all major thunderstorm areas within a radius of approximately 2000 miles from the center of the net with evidence of undershooting beyond. In other words, the project felt at this point that the first problem had been solved; i.e., the origin of sferics fixes is thunderstorm activity.

PART IV

ASSOCIATION OF SFERICS AND SYNOPTIC PATTERNS

(Complete Flash Analysis)

1. Introduction

The same runs discussed above in relation to the direct association studies were used in relating sferics fixes to characteristic synoptic patterns. The purpose of making this synoptic association study is to determine the meteorological worth of sferics data as an aid in synoptic analysis and forecasting, particularly in the absence of much of or all the normal surface data.

The synoptic map-times do not in all cases correspond precisely with the times of the sferics runs, but in five of the ten charts are in deviation by one hour. These synoptic charts (Figures 59 through 60 and 62 through 69) consist of squares containing X's representing fixes and synoptic analyses which were made without knowledge of the fix locations. The following discussions will be primarily concerned with the associations between the fixes and synoptic analyses north of the 25th parallel. Detailed studies for the tropical regions are recommended for future research.

Results of synoptic associations made during July yield the following:

(1) Bands of fixes appear in advance of and parallel to surface

warm fronts indicating thunderstorm activity caused by overrunning.

(2) Bands and lines of fixes have been noted in advance of and parallel to surface cold fronts indicating pre-cold front air mass and/or squall-line activity.

(3) Clusters of fixes are found in cold-air sectors immediately behind cold fronts indicating either air mass or frontal lifting thunderstorms in that region.

(4) Dense bands of fixes concentrated on certain portions of quasi-stationary fronts are indicative of cyclogenetic activity.

Each synoptic association chart is discussed in detail in the next paragraph. A sequence of five charts is presented for the 6th and 7th of July, a sequence of three charts for the 20th, and individual charts for the 9th and 11th.

2. Discussion of Each Synoptic Association Chart

Figure 59 - 060730Z July 1951, 313 fixes, map time - 0630Z. A dense band of fixes is oriented parallel to and predominantly north of the warm front through the Midwest, indicating thunderstorm activity caused by overrunning. A loose band of fixes "brackets" the cold front off the east coast, indicating pre-cold front air mass activity and instability thunderstorms within the cold air sector. The relatively dense block of fixes located off the Carolina coasts is difficult to explain unless this activity is indicative of cyclogenesis in this region. These fixes and the former ones are verified by ship reports of cumulonimbi and lightning.

If these sferics data were the only weather reports available for this area, it appears quite likely that the causal synoptic situation could have been deduced -- the NW-SE orientation of the fixes in the Midwest suggesting warm frontal activity and the NE-SW orientation of the fixes off the east coast suggesting the presence of a cold front.

Based upon the sferics data for this map and the next, it appears that the northern portion of the cold front in the Atlantic might well have been displaced eastward of its indicated position which is based upon scanty reports in this region without the benefit of sferics data.

Figure 60 - 061330Z July 1951, 453 fixes, map time - 1230Z. This map presents the six-hour displacement of the frontal system described above. Sferics fixes are grouped and oriented with respect to the frontal pattern essentially the same as in the last instance. Greater frequencies, however, occur off the coasts of

Georgia and South Carolina than was evident for the preceding map in association with the southern extremities of the cold front. The number of fixes per $1/2^{\circ}$ square run from five to eleven compared with one to three per basic square for other concentrations of fixes appearing on this map. Reference is made to Figure 61 which shows the classic model after Bergeron of a well-developed frontal structure, such as the one under observation. It is noted that the relatively large frequencies of fixes per basic square in Figure 60 are located on a portion of the quasi-stationary front which is the same portion of the model frontal structure which Bergeron classifies as exhibiting anafront characteristics; i.e., strong cyclogenetic activity. The initial intensification by frontogenesis of the quasi-stationary front in Figure 60 was perhaps directly influenced by the greater thermal discontinuity experienced off the Georgia and South Carolina coasts as a result of the Gulf Stream track in this vicinity. Wave formation in this hyperbolic flow region will depend upon the intensity of the organized combination of the warm-air upgliding and the cold-air downgliding along neighboring front sectors (6). The influence of the precipitation processes as personified by the sferics activity may not be overlooked as strong pressure change causes. Although a distinct wave did not form on this portion of the quasi-stationary front, a separate low center might well have been placed in this region.

The fixes north of the warm front in the Midwest are undoubtedly the result of the continued forced ascent of warm, moist air.

Figure 62 - 061530Z July 1951, 407 fixes, three-hourly synoptic data. This map represents a three-hour displacement of the frontal system described above. Sferics fixes are grouped and oriented with respect to the frontal pattern essentially the same as in the last instance with one exception and that is the disappearance of fixes ahead of the cold front in the North Atlantic. This indicates that pre-cold front air mass and/or squall-line activity ceases to exist when the air ahead of the cold front has experienced a substantial trajectory over cool water. An interesting feature of this chart is the even greater frequency of fixes concentrated off the coast of Georgia and northern Florida in association with the frontal structure in that region. This may be attributed to, or may be a cause of, an intensification of the cyclogenetic activity on this portion of the front.

Figure 63 - 070630Z July 1951, 303 fixes, map time - 0630Z. This map represents the synoptic pattern fifteen hours later than that of the last case discussed above. The fixes, which on the past three maps were banded slightly north of the warm front through the Midwest, are displaced a considerable distance north-eastward, and are coincident with an isallobaric minimum. This suggests that a greater amount of lift or overrunning is required in the production

of thunderstorm activity in this particular case. Perhaps, also, a poor analysis was made in this instance, or an upper front is producing the thunderstorm activity. Scattered fixes in the warm sector are probably the result of the strong warm, moist air advection in the lower levels overrun with cold dry air aloft. The orientation and location of the fixes with respect to the cold front in the Atlantic are essentially the same as on the last map with the greater number of fixes appearing behind the cold front. The concentration of fixes off the Florida and Georgia coasts, however, is not as striking in this case as in the last instance. A trough oriented north-south through Florida and Cuba accounts for the remainder of the fixes. Surface synoptic data indicate appreciable isallobaric falls coincident with these fixes.

Figure 64 - 071430Z July 1951, 329 fixes, three-hourly synoptic data. The amount of elapsed time from the last map discussed is eight hours. Fixes associated with the warm front through the Midwest are, as in the last case, located over the Great Lakes region and considerably northeast of the surface front, which now exhibits a distinct bulge in that direction. These fixes are again coincident with an isallobaric minimum. Isolated fixes in the warm sector are undoubtedly the remains of the thunderstorm activity on the previous map. A band of fixes, sparse in some portions, continues to "bracket" the essentially stationary front extending through northern Florida eastward into the Atlantic.

Figure 65 - 091130Z July 1951, 595 fixes, map time - 1230Z. A completely new synoptic pattern exists since considerable time has elapsed between this map and the map discussed above. The particularly dense band of fixes through central Illinois and northern Missouri is associated with cold frontal and quasi-stationary frontal activity in that region. The compact nature of this area of fixes (See Figure 60) suggests strong cyclogenetic activity. A cluster of fixes located off the coast of Florida is located east of a trough and coincident with a field of isallobaric falls.

Figure 66 - 111330Z July 1951, 284 fixes, map time - 1230Z. A dense band of fixes is still coincident with a portion of the essentially stationary front (same as in last instance) oriented east-west through the Midwest. The compact nature of this band of fixes suggests, as in the last instance, future wave formation on that portion of the front. This particular synoptic situation was somewhat unusual because of the persistence of this area of thunderstorm activity with only slight southward movement through seventy-two hours or more. The area of the sferics activity appeared to be a breeding place for a series of small waves or ripples which proceeded eastward along the frontal surface and finally dissipated. A cluster of fixes in the Gulf of Mexico is verified by ship reports of towering cumuli, and a closer analysis of the synoptic data indicates that a trough might well have been placed in this region. The clusters of

fixes located in the southern peripheral region of the sub-tropical Atlantic high and verified by ship reports of towering cumuli, are difficult to explain. Large, developed highs are often, however, characterized by convective activity in the SW sector due to presence of sufficient moisture and rising motion in this sector. Isolated fixes in advance of the NE-SW front off the eastern coast are also verified by ship reports of cumulonimbi and thunderstorms.

Figure 67 - 200030Z July 1951, 592 fixes, map time - 0030Z. This map represents the beginning of a new synoptic series. The synoptic pattern in this case exhibits a squall-line which extends from the northern Gulf Coast northeastward along the eastern seaboard. A broad dense band of fixes is strikingly centered along this line. Although the squall-line cannot be precisely located from the surface synoptic data, the 850-millibar chart shows a long narrow tongue of warm, moist air in the same position. The locations of a substantial portion of the fixes in the Midwest are erroneous, since they have "undershot" the true source region, which is at and beyond the edge of the map (see Part III 4, above).

Figure 68 - 200630Z July 1951, 306 fixes, map time - 0630Z. A six-hour lapse in time has occurred since the last map discussed above. The fixes coincident with the squall-line, which has moved eastward off the coast, have become sparse relative to the dense band noted on the preceding map. Isolated fixes now bracket the surface cold front, indicating that this front is intensifying as the prefrontal squall-line dissipates. Through the Midwest, overrunning associated with a warm front produces a narrow band of fixes which is north of the surface front.

Figure 69 - 201830Z July 1951, 748 fixes, map time - 1830Z. This run had the greatest number of fixes of any plotted in the present series of ten runs, the average being 433. Twelve hours of time have elapsed since the last map-time. The squall-line now produces only a few scattered fixes; it was carried on this synoptic chart on a continuity basis only. Rather, the sferics activity appears to concentrate more on the surface cold front where a loose band of fixes bracket the front, indicating even more definitely than the previous case the intensification of the cold front as the prefrontal squall-line dissipates. A trough over the northern Gulf Coast is marked by a narrow band of fixes of high frequency. By far the greatest frequency of sferics activity on this map coincides with a NE-SW trough passing over southern Florida to the Yucatan. A widespread cluster of fixes is located in the warm sector of an occluded system in the far Midwest. The pattern of these fixes is greatly biased (see Part III 4, above).

3. Remarks on Utilization of Sferics Data

The foregoing synoptic association discussion (complete flash analysis) has brought to light certain interesting relationships

between thunderstorm activity or sferics and characteristic synoptic situations as follows:

a. Warm Fronts - The several cases of warm frontal activity have exhibited compact bands of fixes 200 to 300 miles wide which have appeared parallel to and north of the surface discontinuity. The length of the band (along the surface front) is a direct function of the width of the southerly flow of warm moist air normal to the surface front. The surface isobars, by their spacing and orientation with respect to the surface warm front, give a good estimate of the width of this low level warm advection and thus the length of the thunderstorm band in advance of the warm front. The orientation of these warm frontal bands, in every case, conforms with the average surface front orientation; i.e., from the NW sector to the SE sector. From the sferics band orientation then, warm frontal activity may be deduced. From the width and length of the band, the magnitude and extent of the low level southerly flow may be estimated.

b. Cols, Cyclogenesis, Frontogenesis - Frontogenesis, cyclogenesis, and a pressure col are grouped together here because of their frequently intimate synoptic relationship and because of the pertinent sferics cases under analysis. Compact bands of fixes with the greatest frequency counts per basic $\frac{1}{2}^{\circ}$ square have been noted to be parallel to and coincident with quasi-stationary fronts in regions of hyperbolic flow. Figures 60, 62, 65, and 66 are examples of this situation. In each case the banded structure of the fixes is oriented E-W, in conformity with the predominant orientation of quasi-stationary fronts. In each case, also, the cyclogenetically active portions of the fronts were outlined by the sferics bands.

c. Cold Fronts - Cold fronts are the most difficult to define from a sferics standpoint since there appears to be no intense banded structure of fixes in association with the frontal surface. Exclusive of pre-cold frontal squall lines to be discussed in the next paragraph, sferics fixes appear only to sparsely "bracket" the surface cold front. The orientations of the loose bands are in every case parallel to the surface front, with the majority of the fixes falling behind the front in association with instability conditions within the cold air sector.

d. Squall Lines - Pre-cold front squall lines as defined by sferics activity are generally easy to distinguish (see Figure 67) from the other synoptic situations discussed above. The banded structure is particularly evident and the orientation is predominantly NE-SW in conformity with the average orientation of squall lines.

e. Flow Patterns - If sferics data were to be used in conjunction with little or no other data in synoptic analysis, certain

general features of the flow patterns aloft may be deduced in addition to and in support of the frontal patterns discussed above. Where a dense band of fixes exists, much can be said about the flow aloft. A coincident warm moist tongue must be present at 850 mb perhaps extending to the 700-mb level. Overrunning this low level warm air advection will normally be a cold dry tongue at the 500 mbs level, the two flows intersecting in the three dimensional picture at a large angle (occasionally 90°) in the region of the sferics band. The isotach analyses at upper levels will generally show the region of maximum speed to be along the western and northern edges of the sferics band. If an extensive banded structure is oriented NE-SW, as in the case of squall-line and cold frontal activity, the presence of a major westerly trough may be deduced, displaced slightly westward of the sferics band. If the band is E-W, as in the case of quasi-stationary fronts, the flow aloft is more zonal, but cyclogenetic processes are present. If the band is oriented NW-SE as with warm frontal activity, a minor trough may be deduced with displacement slightly westward of the sferics band.

This discussion of flow pattern aloft may be applied only to sferics structures north of approximately the 25th parallel. Tropical and sub-tropical bands must be treated separately in association with easterly waves, and tropical disturbances.

f. Weather - Not to be overlooked in this deduction process from thunderstorm or sferics data are the conditions of cloudiness, icing, turbulence, hail, rain, lightning, and visibility. The major hazard to flying is thunderstorm activity with all its attendant evils. Where the sferics band exists there can be no doubt about the presence of a solid mass of towering cumuli, cumulonimbi, heavy rain, lightning, severe turbulence, reduced visibility, heavy icing above the $0^{\circ}C$ isotherm, and possible hail. Surrounding the sferics band will be varying amounts of convective cloudiness inversely proportional to the distance from the band itself. The types of cloudiness and the amounts surrounding the sferics bands are also functions of the causal synoptic pattern deduced above.

PART V

DEVELOPMENT OF ADEQUATE SAMPLING TECHNIQUE

1. Introduction

The sferics patterns discussed in Parts III and IV, above, were the results of a complete evaluation of every flash discernible on each two-minute film record. This type of analysis is not operationally feasible because of the time consuming element. It requires

approximately ten hours for 5 people to evaluate the film records containing about 1,000 flashes; the average number of flashes occurring on the film records of the ten runs discussed in Parts III and IV is 1,054. As many as 12,000 flashes have been known to occur on a two-minute film record during a very active summer's day, while 120 flashes may typify an inactive winter's day. The location of the sferics net with respect to thunderstorm producing regions will, of course, have considerable influence on these maximum and minimum figures. The figures noted above are based upon operational experience of the Caribbean Net.

Because of the prohibitive time-consuming element, the question arises as to whether results derived from a sampling of the available data are representative of results gained through a complete analysis. Further, the size of the sample selected must satisfy the requirement for a realistic processing time. The same ten runs discussed previously were used as bases to test the representativeness of the following samples:

a. 250 flashes, Robins station calling, flashes well-defined and evenly distributed through two-minute film record.

b. 200 flashes (same other conditions, as above).

c. 100 flashes (same other conditions, as above).

The time necessary to process 250 flashes is approximately 2½ hours. Beyond three hours, the time element becomes prohibitive. With regard to the condition that the flashes selected be well-defined, this does not mean that only the flashes with large amplitudes were chosen, but rather that the azimuths be reliably determined by the calling station. Since the amplitude of the flash is, in general, an inverse function of the distance between source and detecting station, a mixture of amplitudes, large, medium, and small, were selected in order to insure an adequate area representation. In these respects, the sampling process was purposive in nature.

As mentioned above, the samples were selected from the film records which were fully analyzed and discussed in Parts III and IV. A goal was set whereby a sample is declared adequate if the squares derived therefrom represent 60% of the squares derived from the complete analysis. The statistics of the full analyses are as follows:

Date-Time	No. of Fixes	Estimated Called-Flashes
060730Z July 1951	313	1440
061330Z July 1951	453	1200
061530Z July 1951	407	1080

Date-Time	No. of Fixes	Estimated Called-Flashes
070630Z July 1951	303	840
071430Z July 1951	329	480
091130Z July 1951	595	1320
111330Z July 1951	284	720
200030Z July 1951	592	1920
200630Z July 1951	306	480
201830Z July 1951	748	960
Averages	433	1054

The statistics, above, included counts where more than one fix fell within a basic $\frac{1}{2}^{\circ}$ square. In the sampling study, areal distribution was considered to be of greatest importance and, therefore, the frequency counts of fixes per basic square were eliminated. In other words, the above tabulation was revised to reflect the number of basic squares containing fixes, rather than the actual number of fixes obtained. The number of called flashes was adjusted accordingly on a percentage ratio basis. The following tabulation gives the revised statistics:

Date-Time	No. of Squares Containing Fixes	Estimated No. Called-Flashes
060730Z July 1951	272	1,251
061330Z July 1951	215	570
061530Z July 1951	191	507
070630Z July 1951	262	727
071430Z July 1951	234	341
091130Z July 1951	153	339
111330Z July 1951	212	537
200030Z July 1951	368	1,194
200630Z July 1951	257	403
201830Z July 1951	326	419
Averages	249	629
Total	2,490	6,288

2. Comparison of Samples

It should be noted at the beginning of this sampling evaluation that, since the population (total called-flashes) varies from run to run, the size of the sample expressed as a percentage of the population will also vary. Normally, a sample representing as much as 30 per cent of the population from which it is taken may be considered adequate to serve the purpose for which it is drawn. Viewed in this light, samples composed of 250 and 200 flashes meet this requirement for the large majority of the runs, while the 100-flash sample falls short completely.

To ascertain more practically the representativeness of the samples, the fix distributions or patterns derived from the samples were superimposed upon the fix patterns obtained from the complete analyses. A count was then made of the number of sample fixes which either bordered on or were coincident with fixes from the complete analysis; these sample fixes were denoted as hits, while all others were misses. Since the flashes called in the sampling process were also included in the full analyses, some explanation is required regarding the presence of sample fixes which are classified as misses. Sample fixes which did not border on fixes from the complete analysis were displaced by at least 30 nautical miles. The latter order of magnitude may readily be attributed to human uncertainties in reading azimuths and plotting fixes, particularly in cases of elongated error triangles.

The following table shows the number of hits and misses for each sample:

Date-Time	Flashes in Sample	Fixes obtained from sample	Hits	Misses
060730 Jul '51	250	144	107	37
061330 Jul '51	250	137	111	26
061530 Jul '51	250	125	91	34
070630 Jul '51	250	170	126	44
071430 Jul '51	250	144	110	34
091130 Jul '51	250	114	88	26
111330 Jul '51	250	152	108	44
200030 Jul '51	250	148	121	27

Date-Time	Flashes in Sample	Fixes obtained from sample	Hits	Misses
200630 Jul '51	250	165	109	56
201830 Jul '51	250	125	108	17
Total	2,500	1,424	1,079	345
060730Z Jul '51	200	119	82	37
061330 Jul '51	200	108	80	28
061530 Jul '51	200	73	54	19
070630 Jul '51	200	91	69	22
071430 Jul '51	200	125	95	30
091130 Jul '51	200	108	77	31
111330 Jul '51	200	139	98	41
200030 Jul '51	200	133	115	18
200630 Jul '51	200	127	77	50
201830 Jul '51	200	98	86	12
Total	2,000	1,121	833	288
060730 Jul '51	100	78	50	28
061330 Jul '51	100	54	40	14
061530 Jul '51	100	66	49	17
070630 Jul '51	100	38	25	13
071430 Jul '51	100	72	57	15
091130 Jul '51	100	65	49	16

Date-Time		Flashes in Sample	Fixes obtained from sample	Hits	Misses
111330	Jul '51	100	71	57	14
200030	Jul '51	100	83	74	9
200630	Jul '51	100	57	40	17
201830	Jul '51	100	47	41	6
Total		1,000	631	482	149

The following table shows the degree of difference between the number of fixes classified as hits; that is, the 200-flash sample over the 100-flash sample, and the 250-flash sample over the 200-flash sample:

Date Time		Hits			Percent increase in Hits	
		250 sample	200 sample	100 sample	250 over 200 sample	200 over 100 sample
060730	Jul '51	107	82	50	+30%	+64%
061330	Jul '51	111	80	40	39	100
061530	Jul '51	91	54	49	69	10
070630	Jul '51	126	69	25	83	176
071430	Jul '51	110	95	37	16	67
091130	Jul '51	88	77	49	14	57
111330	Jul '51	108	98	57	10	72
200030	Jul '51	121	115	74	5	55
200630	Jul '51	109	77	40	42	92
201830	Jul '51	108	86	41	26	110
Total		1,079	833	482	+30%	+73%

An examination of the percentages in the above table shows a considerable increase in the number of hits found in the 200-flash sample when compared with the number found in the 100-flash sample. On the other hand, increasing the sample to 250 flashes from 200 flashes brought about a relatively smaller increase, so that the sampling process has approached the point of diminishing returns.

An examination of the number of sample fixes classified as misses will afford some knowledge regarding the human uncertainties in the triangulation procedures. The following table gives this information:

Date Time		Misses			Misses as % flashes in sample		
		250 sample	200 sample	100 sample	250 sample	200 sample	100 sample
060730Z	Jul '51	37	37	28	15%	18%	28%
061330	Jul '51	26	28	14	10	14	14
061530	Jul '51	34	19	17	14	9	17
070630	Jul '51	44	22	13	18	11	13
071430	Jul '51	34	30	15	14	15	15
091130	Jul '51	26	31	16	10	16	16
111330	Jul '51	44	41	14	18	20	14
200030	Jul '51	27	18	9	11	9	9
200630	Jul '51	56	50	17	22	25	17
201830	Jul '51	17	12	6	7	6	6
Total		345	288	149	14%	14%	15%

On a percentage basis, approximately 14% of sample fixes are plotted with errors of the order of 30 nautical miles.

The preliminary information and tabulations, above, do not in themselves insure the adequacy or inadequacy of samples under investigation. The decision as to adequacy should be governed solely by the number of fixes derived from the complete analysis which were coincident with or bordered on sample fixes; that is, a measure of detection. The following table presents the results of this particular count:

DATE TIME		COMPLETE ANALYSIS FIXES	HITS	COMPLETE ANALYSIS FIXES DETECTED BY SAMPLE HITS	COMPLETE ANALYSIS FIXES NOT DETECTED BY SAMPLE	PERCENT COMPLETE ANALYSIS FIXES: DETECTED BY SAMPLE	PERCENT COMPLETE ANALYSIS FIXES: NOT DETECTED BY SAMPLE
250-FLASH SAMPLE							
060730Z	Jul '51	272	107	150	122	55%	45%
061330	Jul '51	215	111	135	80	63	37
061530	Jul '51	191	91	125	66	65	35
070630	Jul '51	262	126	166	96	63	37
071430	Jul '51	234	110	160	74	68	32
091130	Jul '51	153	88	105	48	69	31
111330	Jul '51	212	108	135	77	64	36
200030	Jul '51	368	121	216	151	59	41
200630	Jul '51	257	109	112	145	44	56
201830	Jul '51	326	108	197	129	60	40
Total		2,491	1,079	1,501	989	60%	40%
200-FLASH SAMPLE							
060730Z	Jul '51	272	82	116	156	43%	57%
061330	Jul '51	215	80	117	98	54	46
061530	Jul '51	191	54	108	83	56	44
070630	Jul '51	262	69	141	121	54	46
071430	Jul '51	234	95	146	88	62	38
091130	Jul '51	153	77	98	55	64	36
111330	Jul '51	212	98	134	78	63	37
200030	Jul '51	368	115	204	164	56	45
200630	Jul '51	257	77	108	149	42	58
201830	Jul '51	326	86	175	151	54	46
Total		2,490	833	1,347	1,143	54%	46%

DATE TIME		COMPLETE ANALYSIS FIXES	HITS	COMPLETE ANALYSIS FIXES DETECTED BY SAMPLE HITS	COMPLETE ANALYSIS FIXES NOT DETECTED BY SAMPLE	PERCENT COMPLETE ANALYSIS FIXES DETECTED BY SAMPLE	NOT DETECTED BY SAMPLE
100-FLASH SAMPLE							
060730Z	Jul '51	272	50	93	179	34%	66%
061330	Jul '51	215	40	80	135	37	63
061530	Jul '51	191	49	88	103	46	54
070630	Jul '51	262	25	76	186	29	71
071430	Jul '51	234	37	113	121	48	52
091130	Jul '51	153	49	85	68	54	44
111330	Jul '51	212	57	97	115	46	54
200030	Jul '51	368	74	164	204	45	55
200630	Jul '51	257	40	70	187	27	73
201830Z	Jul '51	326	41	134	192	41	59
Total		2,490	482	1,000	1,490	40%	60%

When setting up the sampling study, it was assumed that a 60% detection of the complete analysis fixes could be considered as a proper measure of adequacy of a sample. Taking this into consideration, it is noted that, as a group, the 100-flash and the 200-flash samples do not meet the standard of adequacy. This is particularly true of the 100-flash sample. The 250-flash sample fails to meet the standard of adequacy in only three of the ten runs; namely, 55% for 060730Z, 59% for 200030Z, and 44% for 200630Z. The relatively low detection in the first two cases (55% and 59%) probably stems from the fact that the 250-flash sample in these instances represented only 20 and 21% respectively of the total population. The low detection for the 200630Z run (44%), when analyzed from all points of view, seems to be due to poor judgment in selecting the flashes to be included in the sample. In other words, a sample cannot be better than the poorest judgment used in its selection.

The same data as in the last table were reorganized on an areal basis, and the following table gives these results:

Longitude	% Distribution, complete analysis fixes	Complete analysis fixes	Sample hits	Complete analysis fixes detected by sample hits	Complete analysis fixes not detected by sample	Perfect complete analysis fixes: Detected by sample	Perfect complete analysis fixes: Not Detected by sample
			250-FLASH SAMPLE				
> 105	1%	20	5	8	12	40%	60%
105- 100	3	73	23	26	47	36	64
100- 95	9	214	114	134	80	63	37
95- 90	13	336	162	224	112	67	33
90- 85	14	339	157	219	120	65	35
85- 80	16	399	172	258	141	65	35
80- 75	19	475	210	296	179	62	38
75- 70	9	234	93	126	108	54	46
70- 65	8	211	79	116	95	55	45
65- 60	5	136	50	75	61	55	45
60- 55	1	27	8	8	19	30	70
55- 50	1	24	6	11	13	46	54
50- 45	1	2	0	0	2	0	100
Total	100%	2,490	1,079	1,501	989	60%	40%
			200-FLASH SAMPLE				
> 105	1%	20	1	1	19	5%	95%
105- 100	3	73	11	16	57	22	78
100- 95	9	214	70	90	124	42	58

Longitude	% Distribution, complete analysis fixes	Complete analysis fixes	Sample hits	Complete analysis fixes detected by sample hits	Complete analysis fixes not detected by sample	Perfect complete analysis fixes: Detected by sample	Perfect complete analysis fixes: Not detected by sample
95- 90	13	336	121	206	130	61	39
90- 85	14	339	112	184	155	54	46
85- 80	16	399	159	262	137	66	34
80- 75	19	475	165	280	195	59	41
75- 70	9	234	81	111	123	47	53
70- 65	8	211	68	114	97	54	46
65- 60	5	136	31	65	71	48	52
60- 55	1	27	8	9	18	33	67
55- 50	1	24	6	9	15	27	63
50- 45	1	2	0	0	2	0	100
Total	100%	2,490	833	1,347	1,143	54%	46%
			100-FLASH SAMPLE				
>105	1%	20	1	1	19	5%	95%
105- 100	3	73	6	6	67	8	92
100- 95	9	214	37	76	138	36	64
95- 90	13	336	73	144	192	43	57
90- 85	14	339	55	150	189	44	56
85- 80	16	399	80	191	208	48	52
80- 75	19	475	110	205	270	43	57

Longitude	% Distribution, complete analysis fixes	Complete analysis fixes	Sample hits	Complete analysis fixes detected by sample hits	Complete analysis fixes not detected by sample	Perfect complete analysis fixes: Detected by sample	Not detected by sample
75- 70	9	234	39	77	157	33	67
70- 65	8	211	40	75	136	36	64
65- 60	5	136	30	59	77	43	57
60- 55	1	27	6	9	18	33	67
55- 50	1	24	5	7	17	29	71
50- 45	1	2	0	0	1	0	0
Total	100%	2,490	482	1,000	1,490	40%	60%

The above table demonstrates clearly the inverse relationship which exists between detection by the sample and distance from the center of the sferics net. This is due primarily to human plotting errors within elongated error triangles which result when baseline length becomes small with respect to distance between source and the center of the net. The relatively poor percentage detection by the sample at great distances may also be due in part to the reluctance of observers to choose the smaller flashes in place of the larger and more well-defined flashes.

The following table shows the percentage increase in detection from one sample to another:

Longitude	Complete Analysis Fixes Detected by: 250 sample	200 sample	100 sample	Percentage Increase in Detection: 250 over 200 sample	200 over 100 sample
>105	8	1	1	+700%	+ 0%
105-100	26	16	6	62	167
100- 95	134	90	76	49	18
95- 80	224	206	144	9	43
90- 85	219	184	150	19	23
85- 80	258	262	191	- 2	37
80- 75	296	280	205	6	37
75- 70	126	111	77	11	44
70- 65	116	114	75	2	52
65- 60	75	65	59	15	10
60- 55	8	9	9	-12	0
55- 50	11	9	7	22	29
50- 45	0	0	0	0	0
Total	1,501	1,347	1,000	11%	35%

The raising of the 100-flash sample to 200 flashes brought about a substantial increase (35%) in the percentage detection. On the other hand, raising the sample from 200 flashes brought about only an 11% increase where a proportionate extrapolation would call for an increase of 17.5%. A point of diminishing returns has been reached where increasing the sample to 300 flashes would yield a percentage increase which approaches negligibility. In other words, the percentage increase would not justify the further expenditure of time for processing the data.

3. Conclusions

Percentages representing the proportion of complete analysis fixes detected by sample fixes show that the sample based on the selection of 250 flashes meets generally the 60% requirement on both a time and areal basis. Further, the time necessary to process 250 flashes is approximately two and one-half hours which is well within the operational limitations prescribed.

An examination of percentage detection versus size of sample leads to the conclusion that the raising of the 250-flash sample to one composed of 300 flashes would not, in all probability, tend to bring about a comparable increase in the number of complete analysis fixes detected by the sampling method. Further, the increase to 300 flashes would bring the processing time to approximately three hours which is the operational limit if runs are to be made every three hours. The safety factor of one-half hour which the 250-flash sample affords far outweighs the essentially negligible percentage detection increase which is offered by the 300-flash sample.

An evaluation of results obtained from samples, purposive in character, should take into consideration the ability of the person selecting the sample. A purposive sample cannot be better than the poorest judgement used in its selection. A case in point is the run for 200630Z July 1951 with a 44% detection. Poor judgment may readily account for this relatively low percentage detection by the 250-flash sample.

PART VI

DIRECT ASSOCIATION OF SFERICS AND THUNDERSTORMS UTILIZING 250-FLASH SAMPLE

1. Introduction

Part III, above, dealt with a direct association of sferics and thunderstorms utilizing the complete flash analysis. Since the latter analysis is not operationally feasible from a time-consuming

aspect, Part V, above, was intended to show that a 250-flash sample is reasonably representative of the full analysis and is within the operational time processing limit. The bases for the sample study in Part V were the ten runs previously discussed in some length in Parts III and IV. It was felt desirable that an independent check be made of the adequacy of the 250-flash sample.

For this purpose the following five station runs (250-flashes) are included as Figures 70 through 89:

Date Time	Date	Figure No.
1230Z	2 July 1951	70
1630Z	2 July 1951	71
1730Z	3 July 1951	72
1130Z	10 July 1951	73
1730Z	10 July 1951	74
0630Z	11 July 1951	75
1730Z	11 July 1951	76
1830Z	14 July 1951	77
1830Z	15 July 1951	78
2130Z	18 July 1951	79
1230Z	19 July 1951	80
0730Z	20 July 1951	81
0830Z	20 July 1951	82
0930Z	20 July 1951	83
1030Z	20 July 1951	84
1130Z	20 July 1951	85
1430Z	20 July 1951	86
1530Z	20 July 1951	87
1930Z	20 July 1951	88
2030Z	20 July 1951	89

2. Discussion of Results

No statistical study was undertaken for the twenty runs listed above. A visual inspection shows that the fixes derived from the 250-flash sample adequately detected all major thunderstorm areas. Some evidence of the fixes undershooting the source regions was apparent when these regions were located in the far midwest. No area of fixes existed without verification by a coincident or neighboring area of thunderstorms. Scattered fixes not verified and scattered thunderstorms not detected were negligible in comparison with the major areas.

The results of the sampling study in Part V appear to be well-substantiated. In other words, the 250-flash sample appears adequate in the light of this independent check, particularly so since the check was made during a month when sferics activity is a maximum.

PART VII

ASSOCIATION OF SFERICS AND SYNOPTIC PATTERNS UTILIZING 250-FLASH SAMPLE

1. Introduction

As a further check on the adequacy of the 250-flash sample and also as a source of further information on the utilization of sferics data, the following synoptic series with associated sferics fixes are presented as Figures 90 through 158 as follows:

a. Series I

Date-time	Figure No.
0030Z 25 April 1951	90
0630Z 25 April 1951	91
1230Z 25 April 1951	92
0630Z 26 April 1951	93
0030Z 27 April 1951	94
0630Z 27 April 1951	95
1230Z 27 April 1951	96

b. Series II

Date-time	Figure No.
0030Z 16 May 1951	97
1230Z 16 May 1951	98
1830Z 16 May 1951	99
1830Z 17 May 1951	100
0030Z 18 May 1951	101
1230Z 18 May 1951	102
1830Z 18 May 1951	103

c. Series III

Date-time	Figure No.
1230Z 4 August 1951	104
1830Z 4 August 1951	105
0030Z 5 August 1951	106
1230Z 5 August 1951	107
1830Z 5 August 1951	108
1230Z 6 August 1951	109

d. Series IV

Date-time	Figure No.
0030Z 10 September 1951	110
0630Z 10 September 1951	111
1230Z 10 September 1951	112
1830Z 10 September 1951	113
0030Z 11 September 1951	114
0630Z 11 September 1951	115
1230Z 11 September 1951	116
1830Z 11 September 1951	117
0030Z 12 September 1951	118
0630Z 12 September 1951	119
1230Z 12 September 1951	120

e. Series V

0030Z 17 October 1951	121
0630Z 17 October 1951	122
1830Z 17 October 1951	123
0030Z 18 October 1951	124
1230Z 18 October 1951	125
0030Z 19 October 1951	126
1830Z 19 October 1951	127

f. Series VI

0030Z 22 November 1951	128
1230Z 22 November 1951	129
1830Z 22 November 1951	130
0030Z 23 November 1951	131
0630Z 23 November 1951	132
1830Z 23 November 1951	133

g. Series VII

1230Z 3 December 1951	134
1830Z 3 December 1951	135
0030Z 4 December 1951	136
0630Z 4 December 1951	137
1230Z 4 December 1951	138
1230Z 5 December 1951	139

h. Series VIII

0030Z 11 January 1952	140
1830Z 11 January 1952	141
0030Z 12 January 1952	142
0630Z 12 January 1952	143
1230Z 12 January 1952	144
1830Z 12 January 1952	145
0630Z 13 January 1952	146

i. Series IX

Date-time	Figure No.
1230Z 1 February 1952	147
1830Z 1 February 1952	148
0030Z 2 February 1952	149
0630Z 2 February 1952	150
1230Z 2 February 1952	151
0030Z 3 February 1952	152
0630Z 3 February 1952	153
1830Z 3 February 1952	154
0030Z 4 February 1952	155
1230Z 4 February 1952	156
1830Z 4 February 1952	157
0030Z 5 February 1952	158

Detailed discussions of each series will be presented in the next paragraph. Synoptic association charts for July were discussed in Part IV, above. Charts for March and June were not prepared. Thus, the following discussions will cover the remaining months of the year. Predominantly, then, these discussions will deal with the sferics and synoptic association for the fall and winter months of the year when sferics activity is often considered negligible beyond the tropical and sub-tropical latitudes. Undoubtedly, the sferics fixes derived from regions north of, say 20°N are reduced in number during the winter months, but when these fixes do appear the significance which may be attached to them becomes great.

The fall and winter series to be discussed were chosen essentially at random with no knowledge of the distribution of sferic fixes. The results in every instance are not greatly favorable to sferics as aids in synoptic analysis and forecasting in the absence of other data, but a forecaster armed with (1) knowledge of the synoptic climatology of the region, (2) continuity of sferics data, and (3) an understanding of the conditions necessary for thunderstorm production can utilize the sferics information to great advantage.

2. Discussion of Individual Synoptic Series

a. Series I - Figure 90 for 250030Z April 1951 shows a sparse band of fixes bracketing the quasi-stationary front oriented E-W through the Midwest. From previous discussions in Part IV, wave formation should be expected in this region, as was borne out by subsequent analyses. From the orientation of the fixes (E-W), one would expect the flow pattern aloft to be of the high index type and, thus, when the wave forms, it should move eastward rapidly, all of which was borne out by subsequent analyses. A widespread area of fixes in the Caribbean is indicative of easterly wave activity in that region.

Figure 91 for 250630Z April 1951 shows the band of fixes in the Midwest bracketing the incipient wave. Fixes in the Caribbean are again associated with easterly waves.

Figure 92 for 251230Z April 1951 shows the wave in the Midwest developed almost to the stage of a closed low center. The sferics activity in association has diminished due in part to the diurnal variation in such activity. The Caribbean fixes persist.

Figure 93 for 260630Z April 1951 shows the large displacement of the wave during the last eighteen hours in accordance with the high index pattern aloft. Only slight deepening has taken place and no fixes are associated with the closed low center. The small cluster of fixes behind the trailing cold front is indicative of instability thunderstorms in the cold air sector. The band of fixes, oriented NE-SW, in the Louisiana region would be indicative of pre-cold frontal squall line activity. The widespread area of fixes in the Caribbean is still associated with easterly waves on the back side of the Atlantic high.

Figure 94 for 270030Z April 1951 shows a dense block of fixes on the east coast which might be interpreted as cyclogenesis in this region of the pressure col following in the wake of the wave now located off Nova Scotia. An insignificant ripple did develop on subsequent maps. A more interesting feature of this chart is the band of fixes, oriented NW-SE, in the Far Midwest. This orientation is suggestive of warm frontal activity and possibly, then, of the occurrence of another wave as number two in a series.

Figure 95 for 270630Z April 1951 shows a widespread band of fixes in the Midwest. The orientation has shifted from the preceding map to one with a NE-SW line. This would probably be confusing to an analyst since the orientation now would be suggestive of cold frontal activity. The exact nature of the disturbance and the exact placement of the frontal system would probably not be clear in this instance. One thing should be certain, however, and that is the changing of the zonal pattern to one with more meridional flow within this region.

Figure 96 for 271230Z April 1951 shows a block of fixes in the Midwest which would aid the forecaster in reaching a decision on the nature of the disturbance. Cyclonic activity would be indicated, and a wave should be placed in this region. The occurrence of small clusters of fixes to the north and south of the main area would substantiate the shift to a more meridional flow. It must be remembered, in this instance, that the sferics activity is reduced due to diurnal effects. More significance may thus be placed on the smaller clusters.

b. Series II

Figure 97 for 160030Z May 1951 shows a band of fixes with a

NNE-SSW orientation in the Midwest. This band would be suggestive of (1) squall line activity and (2) strong meridional low level circulation in this region. The fixes along the Gulf Coast and in Mexico would be further indication of e strong southerly flow of warm, moist air receiving orographic lift. The cold front and shear line, which extends from the low north of Haiti to the Yucatan, is bracketed by sferics fixes primarily near land masses. This would indicate that the air is convectively unstable, and sufficient lift to produce thunderstorm activity, is only obtained with orographic lift.

Figure 98 for 161230Z May 1951 shows diminished activity in the Midwest due to (1) dissipation of the squall line and (2) diurnal effects. A small block of fixes off the Carolina-Georgia coasts appearing at this time of day (0730 local) and with no past history might serve as a warning of cyclogenesis in this region. The loose band of fixes in the Caribbean is still in association with the shear line and a pronounced 700mb trough.

Figure 99 for 161830Z May 1951 shows somewhat increased activity in the Far Midwest in the form of an E-W band which would suggest that a quasi-stationary front is coincident with and parallel to this band with cyclogenesis taking place. The frontal pattern, in this instance, is diffuse, and the orientation of the quasi-stationary front is askew in relation to the position indicated by the sferics band. A wave did develop on subsequent maps but somewhat to the north of the band and with questionable relationship to this band. The small block of fixes off the Carolina-Georgia coasts is still evident on this chart and should particularly indicate cyclogenetic processes in view of the time of day (1330 local) and the water locale. Shear lines account for the Caribbean fixes.

Figure 100 for 171830Z May 1951 represents a 24-hour lapse in time from the preceding map. The dense band of fixes south of the Great Lakes is oriented parallel to and coincident with an E-W quasi-stationary front through this region. The orientation and character of this band would, according to previous experience, indicate cyclogenesis, which materialized in the form of a wave on subsequent maps. The sferics activity in the Far Midwest has dissipated to a large extent, and the frontal pattern is weak and diffuse. The cyclogenesis which was indicated on the last map in the region off the southeast coast has produced an intense closed low center with a block of fixes in attendance. Shear lines account for the fixes in the Caribbean area.

Figure 101 for 180030Z May 1951 shows decreased activity south of the Great Lakes with wave formation being indicated by a slight cyclonic curvature of the isobars in this region. A loose band of fixes in the Far Midwest bracket an E-W incipient wave. A scatter of fixes south of this region are associated with a dissipating discontinuity. The closed low off the SE coast has moved slightly

southward during the past six hours, and a block of fixes lies in the SE quadrant. A smaller block of fixes appeared for the first time to the NE of this region. This new activity would be indicative of a secondary center of cyclogenesis which is present, according to the analysis, somewhat NE of the sferics fixes. The pattern of sferics in the Caribbean area remains essentially the same as in the last instance.

Figure 102 for 181230Z May 1951 shows a diffuse wave in the Far Midwest with no sferics fixes in attendance. The lack of sferics is due, in part, to diurnal effects. The low center off the SE coast has persisted with a block of fixes coincident. The secondary low has deepened and moved northward with a block of fixes located in the NW quadrant. Waves appear to be forming (1) on the E-W quasi-stationary frontal system west of the low center and (2) at the point where the low center is merging with the quasi-stationary front. An interesting feature of this map is the appearance of a third block of fixes to the SSE of Bermuda indicating that this might be a third low center following in the wake of the secondary center. Shear lines account for fixes in the Caribbean area.

Figure 103 for 181830Z May 1951 shows clusters of fixes appearing in the Far Midwest in association with the weak frontal system in this region. A block of fixes is still coincident with the low center off the SE coast. The secondary low center has moved slowly eastward during the last six hours and a small block of fixes appears in the N quadrant. An even smaller block of fixes is associated with a minor wave on the quasi-stationary front south of the Great Lakes. The block of fixes SE of Bermuda has persisted and become larger in extent. Although the analysis does not show a third low center in this region, the sparseness of the synoptic data might have caused the analyst to miss this tertiary cyclogenesis. The pattern of fixes in the Caribbean remains essentially the same.

c. Series III

Figure 104 for 041230Z August 1951 shows a band of fixes along the east coast. This band is essentially parallel to and lies in advance of a cold front in this region. A series of loose bands in the Caribbean are coincident with easterly waves. No fixes are present around hurricane "Baker" located just east of Bermuda nor are reports of thunderstorms evident. Except in the initial stages, little, if any, thunderstorm activity closely attends hurricane activity. The NE-SW orientation of the band of fixes off the east coast would suggest a fairly strong westerly trough and low index pattern aloft which is borne out on the 700mb map.

Figure 105 for 041830Z August 1951 shows the band of fixes along the east coast becoming diffuse in the northern sector and reorienting itself on an E-W plane in the southern portion. The cold front has become quasi-stationary in the southern portion, and the

band of fixes lies in advance of and parallel to this portion of the front. Future wave formation should be forecast and would verify on subsequent maps. Because of the more zonal orientation of the band of fixes, the pattern aloft in this region may be deduced as becoming more zonal in relation to the preceding case. Sferics activity in the Caribbean area has diminished indicating a weakening of easterly wave activity.

Figure 106 for 050030Z August 1951 shows a merging of the band of fixes in the SE with easterly wave activity. The most important part of this map is the first appearance of a loose NW-SE band of fixes in the Far Midwest which would suggest to the analyst the presence of warm frontal activity to the southwest of the fixes.

Figure 107 for 051230Z shows a strengthening of the NW-SE band of fixes in the Far Midwest, which fact would further substantiate the presence of warm frontal activity in this region. A small wave has developed on the quasi-stationary front off the SE United States, with a small band of fixes still bracketing this frontal region. Easterly wave activity still accounts for bands of fixes in the Caribbean area.

Figure 108 for 051830Z August 1951 exhibits considerably decreased sferics activity associated with the warm front in the Far Midwest. The quasi-stationary front in the SE United States is still bracketed by a sferics band which appears to merge with easterly wave activity which extends from Florida to the Yucatan.

Figure 109 for 061230Z August 1951 shows a block of fixes SW of Lake Michigan and in a region of warm frontogenesis. The decreased sferics activity in the SE United States agrees well with the dissipating frontal action in this region. Easterly waves in the Caribbean might well have been placed more accurately through utilization of the sferics data.

d. Series IV

Figure 110 for 100030Z September 1951 shows a widespread band of fixes oriented diffusely E-W through the south Midwest. As first in a series with no past history, this band of fixes might be difficult to interpret. In reality, the fixes are caused by cold frontal, warm frontal, and squall-line activity all merged into one mass. Although the exact nature of the causal frontal pattern may not easily be deduced in this instance until a continuity is established, the nature of the band and its orientation do suggest a relatively zonal flow aloft which is evident on the 700mb chart. A rhythmic series of easterly waves, 36-48 hours apart, characterize the Caribbean area throughout this September synoptic series. Clusters of fixes locate the positions of the easterly waves reasonably well on the map under discussion. These easterly waves are denoted by "E_1", "E_2", "E_3", and "E_4". Subsequent easterly waves developing within the scope of the map will be numbered in sequence. Hurricanes "Easy" and "Fox" in the Atlantic remain undetected by sferics fixes, since little or

no thunderstorm activity accompanies well-developed hurricanes.

Figure 111 for 100630Z September 1951 shows a distinct ENE-WSW band of fixes in the south Midwest where a diffuse, widespread band existed on the previous map. There should be no doubt in this case that this band is the result of cold frontal and squall-line activity in this region. Also, since the slope of the band with respect to the E-W plane is not great, a relatively zonal flow aloft may be deduced, and consequently the speed of movement of this squall-line should be forecast as being relatively fast. A scatter of fixes appears behind the frontal system to the north indicating instability thunderstorms within the cold air sector. With the exception of "E_4", sferics fixes in the Caribbean are grouped so as to delineate the easterly waves, and perhaps to a more accurate degree than is afforded by the analysis derived from the sparse synoptic data in that region. One fix appears in the SE quadrant of Hurricane "Fox" located off the coast of Newfoundland; and several fixes appear in the SE quadrant of Hurricane "Easy".

Figure 112 for 101230Z September 1951 shows a substantial displacement of the band of fixes in the south Midwest during the past six hours. The band brackets the squall line, while no sferics activity is associated directly with the surface cold front which appears to be dissipating. The band of fixes coincident with "E_1", merges with the squall line activity on the Gulf Coast. "E_3" is more active from a sferics standpoint than "E_2", and "E_4" has no sferics fixes in attendance. Two fixes appear to the north of Hurricane "Easy".

Figure 113 for 101830Z September 1951 shows, again, a large displacement eastward of the squall-line band of fixes which tends to merge with the band associated with "E_1" along the Gulf Coast. Perhaps because of the nearness of this large and intense area of fixes to Robins and MacDill, sferics data from other areas were blanked out at these stations. At least, little sferics data is associated with easterly waves "E_2" and "E_3", where substantial numbers of fixes existed previously. No sferics data are associated with Hurricane "Easy".

Figure 114 for 110030Z September 1951 shows the band of fixes associated with the squall line to be completely merged with the fixes attending "E_1". The squall line appears to be dissipating. Bands of fixes are oriented parallel to easterly waves "E_2" and "E_3", but "E_4" remains undetected. Clusters of fixes along the ITC indicate the strong points of the zone, while the absence of fixes indicate the weak portions.

Figure 115 for 110630Z September 1951 shows the squall-line activity to be completely dissipated. Also, "E_1" has, for all purposes, vanished. "E_2" has strengthened as is evident from the extensive band of fixes in attendance. From the location of this band, it appears that the position of "E_2" should have been displaced

northward since convective phenomena normally follow easterly waves rather than precede them in space. "E_3" is well bracketed by a band of fixes, but "E_4" is undetected. Clusters of fixes are present along the westerly trough which extends southwestward from Hurricane "Easy."

Figure 116 for 111230Z September 1951 shows extensive bands of fixes parallel to and coincident with "E_2" and "E_3", while "E_4" remains undetected. Little or no sferics data have been in association with the latter easterly wave, and its existence might well be questioned. The band of fixes which has existed for the past 12 hours in the Panama Gulf may be the result of what this locality calls the "Yellow or Panamanian Front". A very definite band of fixes appears along the westerly trough in the Atlantic where only small clusters existed previously.

Figure 117 for 111830Z September 1951 shows somewhat decreased activity in association with "E_2" and "E_3", but the banded structures are still present for identification purposes in the absence of other data. A thin band of fixes continues to outline the westerly trough in the Atlantic. The so-called Panamanian Front appears to be dissipating.

Figure 118 for 120030Z September 1951 shows "E_2" and "E_3" to be well detected by bands of sferics fixes as both progress in an arc northward toward the Gulf Coast. Decreased sferics activity attending the westerly trough in the Atlantic indicates weakening of this system. A new cluster of fixes appearing in the Midwest should be looked upon as a forerunner of frontal activity in this region, the exact nature of the disturbance being indistinct at this map time.

Figure 119 for 120630Z September 1951 shows "E_2" to be dissipating while "E_3" remains well detected by a band of fixes. "E_5" and "E_6" have formed and are reasonably detected by clusters of fixes. The Panamanian Front has become active again as is evidenced by the return of a block of fixes in that region. Only a small cluster of fixes remains associated with the dissipating westerly trough in the Atlantic. By far the most important sferics activity on this chart is the extensive, widespread NE-SW band which lies primarily in advance of the cold front in the Midwest. A small cluster of fixes on the preceding map was the forerunner of this extensive activity. The causal frontal pattern could not be mistaken, in this instance, if only sferics data were available. In addition, the orientation and extent of this band would clearly indicate an intense trough aloft as the 700mb chart clearly shows.

Figure 120 for 121230Z September 1951 shows increased activity along "E_2" while "E_3" has dissipated. "E_5" has merged with the Panamanian Frontal activity in the Gulf of Panama. There has been a certain rhythmic cycle in the Panamanian Gulf activity. The extensive band in the Midwest has moved eastward and remains essentially intact with the exception of a slight break in the northern portion.

It is probable that the separated block of fixes to the north might well be associated with warm frontal overrunning. In this case, the position of the warm front, as analyzed, is displaced too far north.

e. Series V

Figure 121 for 170030Z October 1951 shows a predominance of sferics activity in the lower latitudes as might be expected during the late fall and winter months. Much more significance must now be placed upon sferics fixes when they occur north of approximately the 30th parallel. For instance, during a summer month the occurrence of only two fixes such as over Lake Michigan on the present map would require only a cursory examination and would be tentatively disregarded as being indicative of frontal activity. In the present month of October, much more attention must be paid to these isolated clusters of fixes in the more northern latitudes. Frontal activity must be deduced, although the exact nature of the system would not easily be determined in this instance. Easterly wave activity accounts for the band in the Caribbean area. Only one fix appears in the SE quadrant of the hurricane in the Atlantic.

Figure 122 for 170630Z October 1951 shows increased activity in the Midwest and the localized nature of the small cluster of fixes should suggest cyclogenesis in this region. Isolated fixes appear in the western portion of the Atlantic hurricane and in the southern portions of the high cell centered over Newfoundland. Easterly waves account for bands of fixes in the Caribbean area.

Figure 123 for 171830Z October 1951 shows further increases in the number of fixes in the Midwest which should substantiate to the analyst the presence of cyclogenetic processes. For the first time in this series a substantial cluster of fixes appear in the northern portion of the Atlantic hurricane. In the absence of other data, this would also indicate cyclogenetic processes to the analyst. Easterly waves account for the fix distribution in the Caribbean area, although the analysis does not seem to "jibe" with the sferics bands.

Figure 124 for 180030Z October 1951 shows no fixes associated with the frontal system through the Midwest and the discontinuity has thus become weak. An abundance of fixes appear in the north and east portions of the Atlantic hurricane, and although the analyst might not deduce hurricane activity, the persistence of this area of fixes would suggest strong cyclogenetic processes. Easterly wave activity with associated sferics bands continue to dominate the Caribbean area, and again the analysis looks poor in relation to the positions of the sferics structures.

Figure 125 for 181230Z October 1951 shows continued intense sferics activity in a band from the north to the east portion of the Atlantic hurricane. Much the same conditions prevail in the Caribbean

area. The appearance of a small block of fixes near 40°N and 50°W would suggest cyclogenetic activity in this region.

Figure 126 for 190030Z October 1951 shows only one fix in the northern portion of the Atlantic hurricane and one fix north of the low center east of the hurricane. The Caribbean area exhibits essentially the same pattern as discussed previously.

Figure 127 for 191830Z October 1951 is very similar to the last map. The Atlantic hurricane appears to be dissipating with only widely scattered fixes in attendance. The absence of fixes over most of the U. S. area would lead the analyst to believe that high pressure dominates this region, which is reasonably correct since only a week discontinuity is present.

f. Series VI

Figure 128 for 220030Z November 1951 shows a large widespread area of fixes over northern South America and the Caribbean water area in association with a low pressure area and the active portion of the ITC through this region. The low pressure area persists throughout this series and the fix pattern remains essentially the same; thus,no further mention will be made regarding the Caribbean area in this discussion of the November series. The NE-SW band of fixes in the Atlantic on the present map would indicate cold frontal activity, and since pre-cold frontal squall-line activity does not normally exist after the air has experienced a substantial water trajectory, the fixes in this instance should be classified as instability thunderstorms within the cold air sector. With this reasoning, the analyst would thus place the cold front in advance of the band of fixes and parallel to this band, in which case he would arrive at a fairly exact analysis based only upon sferics data. Also, for this band of fixes to appear on a November chart, a strong westerly trough must be present aloft as is evident on the corresponding 700mb chart.

Figure 129 for 221230Z November 1951 shows decreased sferics activity in the Atlantic as the cold front proceeds eastward beyond the scope of the map. Two fixes appearing in the Midwest should cause the analyst to speculate on the cause of this new activity. Subsequent maps should help him in the deduction process.

Figure 130 for 221830Z November 1951 shows increased activity in the Midwest in the form of a very loose band which brackets the frontal system in that region. Perhaps with this orientation of ENE-WSW, a quasi-stationary frontal zone might be the best analysis from a sferics standpoint.

Figure 131 for 230030Z November 1951 shows considerably increased activity in the Midwest with the sferics band orientation of NE-SW strongly suggesting cold frontal activity in this region. It is interesting to note that the largest portion of the sferics band is

located more to the rear of the frontal system which is perhaps typical of winter situations where pre-cold frontal squall lines are not nearly as frequent as in summer situations. There is also a suggestion of cyclogenesis in the present case.

Figure 132 for 230630Z November 1951 shows the band of sferics in the Midwest to be somewhat reduced in extent and with an orientation which has shifted to an E-W plane. This would suggest quasi-stationary frontal activity with cyclogenesis taking place. Also, the flow aloft would be changing to one more zonal in character.

Figure 133 for 231830Z November 1951 shows an absence of fixes in the Midwest along with a weakening of the system. The previously deduced system should, of course, be carried on this map on a continuity basis and subsequent maps examined for the re-occurrence of sferics data to help in determining the fate of the system.

g. Series VII

Figure 134 for 031230Z December 1951 shows a large widespread block of fixes in the south Midwest. This block of fixes would be difficult to interpret since there appears to be no preferred orientation. With no past history, the analyst should assume that a wave is forming in this region in order to be consistent with prescribed interpretations of sferics configurations. Subsequent maps would determine the quality of his judgement. The scattered fixes in the Atlantic would indicate also some cyclonic activities at work. The trough and ridge pattern aloft may easily be deduced with the space between two areas of fixes being filled by a ridge. In view of the wintertime situation, the flow aloft may be considered to be meridional in character in order to produce the thunderstorm activity. Sferics activity in the Caribbean is occasionally diffuse in this December series and will not be discussed in any detail.

Figure 135 for 031830Z December 1951 shows that the sferics activity in the Midwest has assumed a curved configuration with a N-S orientation. A similarly oriented extended cold front should then be deduced by the analyst. The sferics drea in the Atlantic has become only two scattered fixes indicating dissipation of the cyclogenetic processes.

Figure 136 for 040030Z December 1951 shows a small band of fixes bracketing the cold front only in the southern portion. From the presence of fixes in a band much farther north on the previous map, the actual frontal structure in the present instance should be carried on a continuity basis from the preceding deduction. Scattered fixes appear in advance of and behind the cold front.

Figure 137 for 040630Z December 1951 shows only scattered fixes in advance of the southern portion of the cold front through the Midwest. The front may be extrapolated from past measurements of

movement with a fair degree of accuracy. Weakening of the discontinuity would certainly be implied by the lack of sferics data in attendance. A widespread cluster of fixes appears in the Atlantic behind the low center which has moved beyond the scope of the map. These may be difficult to interpret but the scatter would probably be a good indication of cold sector instability.

Figure 138 for 041230Z December 1951 shows again, only scattered fixes in advance of the southern portion of the cold front. Extrapolation from previous maps would need to be relied upon to some extent for the placement of the front. Much valuable information could be gained throughout this December series by the absence of sferics fixes over most of the Caribbean and Gulf areas.

Figure 139 for 051230Z December 1951 represents a 24-hour lapse in time from the previous map. A dense block of fixes brackets a portion of the quasi-stationary front through the southeast United States. Continuity in sferics utilization work is just as important as in normal synoptic analysis, and it is particularly important during wintertime situations. The present sferics block, by itself, would mean little even to an experienced user of sferics data. As a unit, separated in time with other sferics maps, only the fact that a quasi-stationary front exhibiting cyclogenetic activity and passing through the center of the block of fixes would be evident. Subsequent maps would undoubtedly provide information from which the remainder of the synoptic situation might be deduced. For instance, from Figure 134, above, the exact nature of the frontal system was not readily evident, but from Figure 135 (six hours later) the orientation of the sferics band clearly suggested the existence of an extensive cold front.

h. Series VIII

Figure 140 for 110030Z January 1952 would present the analyst with no sferics data north of the 20th parallel, and thus no firm basis for deductions regarding the overall synoptic situation. The Caribbean area throughout this January series is characterized, as in the December series, by rather diffuse sferics activity occurring primarily over the land areas and in convectively unstable air receiving orographic lift. No organized pattern of sferics fixes exists, thus indicating the absence of easterly wave activity in the Caribbean area.

Figure 141 for 111830Z January 1952 shows a N-S loose band of fixes in the Atlantic which, from previous sferics and synoptic climatology, would indicate instability thunderstorms within the cold air sector of an extensive cold front. In addition, future wave formation would be suggested, which was borne out on subsequent maps. Whereas on the previous map no sferics data were present in the northern latitudes and thus little could be deduced concerning the overall synoptic pattern, the sudden appearance of a band in the Atlantic places the trough for the analyst and consequently the ridge to the rear. The two isolated fixes in the high cell over eastern United States

would be difficult to interpret without other data, but fixes in such positions have been verified, at least during summer situations, by actual reports of thunderstorms well within the confines of a high cell.

Figure 142 for 120030Z January 1952 shows the now NE-SW loose band of fixes in the Atlantic displaced only slightly northward from its position six hours previous. This band would further substantiate the previous deduction of instability activity within the cold air sector. As has been mentioned previously, pre-cold frontal squall line activity is essentially non-existent over water areas.

Figure 143 for 120630Z January 1952 shows only one fix in the area in the Atlantic where the band existed six hours previous. From past history in this series and with due regard to a wintertime situation, this sole fix would still serve as a valuable indication of a rather slow movement to the frontal structure. The series of three fixes to the south would aid considerably in placing the southern extremities of the cold front.

Figure 144 for 121230Z January 1952 shows two fixes attending the wave formation on the cold front in the Atlantic. A small group of fixes is again associated with the southern extremities of the front. A group of fixes well in advance of the cold front in its southern portion appears to be associated with a convergent zone in the southeast portion of the Mid-Atlantic high cell.

Figure 145 for 121830Z January 1952 shows increased sferics activity in the form of a block and in association with cyclogenesis on the cold front in the Atlantic. Throughout this January series, up to and including this map, the sferics activity in the Atlantic has remained essentially in the same position indicating to the analyst a relatively stagnant synoptic situation.

Figure 146 for 130630Z January 1952 shows a widespread scatter of fixes in the Atlantic forming an extremely loose band. The wave has intensified during the last twelve hours as might have been expected from the preceding map. The scatter in this instance should indicate a movement of the front more rapid than was evident heretofore. The scatter of fixes west of the high cell could be difficult to interpret without other data, but they might be deduced as being on the back side of a high in the SE quadrant, in which case the analyst would have placed the high cell NE of its true position.

i. Series IX

Figure 147 for 011230Z February 1952 displays a loose band of fixes from Georgia southeast through the Gulf of Mexico. With no other data, this would be interpreted as cold frontal activity both from the NE-SW orientation and the loose banded structure. In this case a fairly poor synoptic analysis would have been made. However, it must

be remembered that this represents the first in a series with no past history to support any deduction process.

Figure 148 for 011830Z February 1952 shows an entirely different sferics distribution picture, which would cause the analyst to reconsider his analysis in the last instance. The block of fixes in the Midwest would be suggestive of cyclogenesis on a portion of a quasi-stationary front through this region. The short band of fixes along the Gulf Coast would be suggestive of a convergent zone of convectively unstable air receiving orographic lift. Strong southerly flow in the lower levels would certainly be a prerequisite for such activity.

Figure 149 for 020030Z February 1952 shows a widespread block of fixes in the south Midwest. As in the last instance, cyclogenesis in combination with a strong convergent zone in the SE quadrant of a high cell would be the only solution for this sferics configuration. The analyst at this stage would certainly have an excellent idea of the trough and ridge locations at the surface and aloft.

Figure 150 for 020630Z February 1952 gives clear evidence of a NE-SW orientation of cold frontal activity in the Gulf area. The solid character of the sferics band would suggest squall-line activity in advance of a cold front. Since cyclogenesis was indicated on the previous two maps, a wave should be carried on this chart.

Figure 151 for 021230Z February 1952 shows the sharp band of fixes displaced eastward leaving no question of squall-line activity. The scattered fixes behind the sferics band would be attributed to the cold front, itself.

Figure 152 for 030030Z February 1952 shows only scattered fixes where the banded structure had existed previously. The squall line would obviously be removed from the analysis, and the cold front carried so as to be bracketed by the scattered fixes.

Figure 153 for 030630Z February 1952 shows, again, only scattered fixes off the coast of Florida and in Georgia, and little information would be gleaned from these. The analyst would need to rely upon extrapolation from past positions of the front in this region. The appearance of scattered fixes as far north as Newfoundland would certainly cause the analyst to place frontal activity in this region.

Figure 154 for 031830Z February 1952 is notable for its absence of sferics data. A deep low developed in the past twelve hours, and with a twelve hour lapse between sferics runs in this instance, was inadequately detected. In any future operational program, it is certainly desirable to operate the sferics equipment on a more frequent basis, say every three hours. The SOP normally calls for runs every six hours. A twelve hour lapse in the present case was undoubtedly occasioned by the malfunction of one or more of the five stations of the net.

Figure 155 for 040030Z February 1952 shows a small block of fixes to the west of the intense low situated off the Carolina coast. Another cluster of fixes appears north of the low center in the south Midwest. These two groups of fixes might have been banded together by the analyst in an WNW-ESE line, in which case a frontal structure thus oriented would have been a first approximation to the true analysis.

Figure 156 for 041230Z February 1952 shows a thin band of fixes from Ohio south to Florida. Cold frontal activity would be deduced, and most certainly a major westerly trough aloft. The small block of fixes in the NE quadrant of the intense low center off the coast of Maryland would be attributed to cyclogenesis in this region.

Figure 157 for 041830Z February 1952 shows a short and narrow NE-SW band of fixes south of the Great Lakes indicating cold frontal activity. Two fixes appear to the east of this region and might be associated with the wave formation suggested in the previous case.

Figure 158 for 050030Z February 1952 shows a widespread block of fixes centered near Washington, D. C. This block and the trailing thin band of fixes extending southwestward to the Yucatan would be strongly suggestive of an intense wave with a trailing cold front. A major westerly trough aloft may easily be deduced from this situation.

3. Remarks on Utilization of Sferics Data

Throughout the discussions in this part of the report dealing with the synoptic and sferics association utilizing the 250-flash sample, the rules promulgated in Part IV from the complete flash analyses were utilized and found to be applicable in the deduction processes.

Additional rules were introduced, such as the significance of NE-SW bands over Atlantic water areas. Since the mechanism of pre-cold frontal squall lines precludes the appearance or persistence of these disturbances over water area, the bands of fixes appearing well off the east coast of the United States are attributed to instability thunderstorms within the cold air sector of a cold front structure, and thus the surface cold front, itself, is placed in advance of such sferics configurations.

Other rules were introduced regarding the relative zonal or meridional character of the flow aloft. The orientation of the sferics pattern gives an accurate indication of the flow index aloft N-S structures being suggestive of low index and E-W configurations of high index.

Easterly waves, particularly during the September series, were identified easily by banded sferics structures which moved in an arc

around the SW quadrant of a high cell. Greater sferics activity generally attended the leading easterly wave with progressively lighter activity attending the rhythmic series which followed.

The importance of attributing more significance to isolated sferics activity occurring during wintertime situations than during the summertime is readily apparent. It is evident, also, that the utilization of sferics data in determining the causal synoptic pattern is much more difficult during relatively quiet months. For the most part, in latitudes north of the 30th parallel in this area and during the late fall and winter, isolated sferics activity must be attributed to frontal activity and not to local air mass thunderstorms as would normally be the proper deduction during a summertime situation. Continuity becomes much more important during the quiet months, since a sferics map, isolated in time, may more easily be misinterpreted during winter than during summer.

PART VIII

DIRECTION FINDING ERRORS

1. Introduction

In Part III 4, above, it was noted that sferics fixes "undershot" source regions when the distance between the source and center of the net becomes great with respect to the station baseline lengths. Reasons suggested for the "undershooting" phenomenon were (1) the inherent instrumental errors, and (2) the parallel beam uncertainty. In an earlier sferics publication of the project (1), it was suggested that a certain amount of error was introduced into the indicated bearings of discharges through a guiding of the electromagnetic waves as they traverse mountainous terrain. This theory was promulgated by the observance during the project investigations of consistent bearing errors at certain stations, particularly when the sferics source regions lay beyond the Appalachian Chain. Recent investigations based upon simultaneous runs at selected stations have resulted in findings which indicate that these consistent bearing errors are due primarily to inherent instrumental errors, and that the guiding effect, if it exists, is negligible in proportion.

In addition to discussions of the directional errors which are inherent in the sferics equipment and which affect the accuracy of a fix, this part of the report will also include some discussions regarding the non-detection of isolated thunderstorm activity.

2. Ideal Network

From considerations of accuracy, the best shape for a three-station net is an "L", thus allowing intersections of minimum closure

("sharpest") in two planes. The ideal shape for a four-station net is a perfect square, for which case the "sharpest" intersections occur within the square. From this consideration and that of the range of each station, the baselines should be equal to $2r/\sqrt{5}$, which will thus permit at least three stations to detect any and all sources within the square. Figure 159 shows the ideal four-station net.

Each station possesses a range capable of necessary variability. The variability depends to a large extent upon the nearness and severity of thunderstorm activity since these factors determine the particular gain setting to be used during a specified run. Before each run, the gain of the equipment is adjusted so that the greatest flashes extend only to the extremity of the scope. This procedure has been adopted in order (1) to limit, as much as possible, the "blanking out" effects due to superposition of large, broad, and occasionally elliptical flashes from nearby storms on the smaller flashes from distant storms, and (2) to obtain accurate azimuthal readings of these large flashes from nearby storms. In so limiting the gain of the sferics set, however, this procedure defeats its purpose to some extent by eliminating the detection of flashes from very distant storms. The procedure is admittedly a compromise, but it affords the optimum conditions for the reception of usable data. Since the gain setting chosen for a given run of an individual station is thus dependent upon the presence or absence of nearby thunderstorm conditions and therefore, variable, it is more desirable to speak of the range of the net from its center point rather than the range of the individual stations. Further, when speaking of the range of a net, one implies that this range is the maximum distance to which accurate fixes may be obtained. For instance, the associations made between data from the Caribbean net and reports of thunderstorm activity indicate that this particular net has a range of accuracy of approximately 2000 miles from the center point.

Although the baselines should be ideally equal to $2r/\sqrt{5}$ (see Figure 159), practical considerations involving the range variability of individual stations and the maintenance of communications between the outlying stations and the net-control station, puts an upper limit on the extent of the baselines.

3. Parallel Beam Uncertainty

The effect of quasi-parallel beams is a function of three factors: namely (1) distance of source region from center of net, (2) baseline length, and (3) orientation of the net with respect to the area to be scanned.

The "undershooting" phenomenon (see Part III 4) occurred when thunderstorm source regions in the Far Midwest were located as distances greater than 2000 miles from the center of the net. At this great distance many of the bearings from the Kindley and Fort Monmouth stations (see Figure 160) would be almost parallel, and more strikingly

so for bearings from the Robins, MacDill and Ramey stations. The multiple intersections of the members of these two parallel beams involving two and three bearings each, respectively, enclose an area which is generally too large to be closed to a single point (see Part III 3). Cases of this doubtful nature were discarded. However, if the Ramey station exhibited a bearing which appeared to be grossly in error, as was often the case, or did not read a particular flash from this storm, which happened occasionally for the weaker flashes in view of the great distance (3000 miles) from Ramey to the source, then the intersections of bearings from Fort Monmouth, Kindley, and Robins would frequently represent the vertices of an elongated triangle (see Figure 161). Because of inherent instrumental errors, to be discussed later in this section, the MacDill station, for this source region and along with the Ramey station, generally exhibited a seemingly erroneous direction. With reference to Figure 161, then, the fix would be placed at the center of the inscribed circle. In this case, the center of the inscribed circle may not be the most representative position for the fix location, since it favors the bearing from the Robins station. Since any position within the triangle is a possible fix location, the fix determined by the center of the inscribed circle in an elongated triangle would consequently tend to "undershoot" the source when compared to the centroid location.

Another factor contributing to the erroneous fixes noted in the Far Midwest and directly related to the great distance between source and net is the uncertainty of fix location produced by the allowable movement of each azimuth to a maximum of $\pm 3^{\circ}$ in seeking a fix (see Part III 3). At a distance of 2500 miles, a three-degree movement of one azimuth corresponds to scanning an arc of approximately 130 miles. In seeking a fix, the allowable movement of $\pm 3^{\circ}$ would thus permit a scan of 260 miles for each azimuth. Such a large leeway detracts appreciably from the accuracy of a fix. If the error triangle in the Far Midwest is small initially, and if all possible fixes are plotted by all combinations of incremental movements of each azimuth up to 3°, a scatter of locations will result which form an elongated elliptical pattern superimposed upon the elongated triangle. The distant end of the elliptical scatter will greatly "overshoot" the source region and the near end will "undershoot".

4. Inherent Instrumental Errors

Throughout the direct association analyses discussed in Part III 4 and Part VI 2, above, consistent bearing errors were noted for particular stations and for particular source regions. For instance, the MacDill station appeared to have a consistent bearing error when the storm area was located in the Far Midwest; the error being approximately -5° from the apparent true bearing as determined from the location of the fix derived from bearings of the Fort Monmouth, Robins, and Kindley stations. The Ramey station also appeared to have a consistent bearing error in this case of $+10^{\circ}$ from the apparent true bearing of the storm. The Fort Monmouth station appeared to have

consistent bearing errors in the southwest quadrant when the storm area was located in the region of the Gulf of Mexico. The Robins station was noted to have consistent errors in the NE quadrant. Finally, the Bermuda station appeared to have no consistent bearing errors. The guiding effect of the mountainous terrain paralleling the east coast seemed to offer a reasonable explanation for the discrepancies noted. In order to check this theory by the process of elimination, simultaneous observations utilizing a spare sferics set and the normal station set were made with the spare set (1) at the local and two remote sites at Ramey, (2) at a remote site at Kindley, and (3) at the local site at MacDill. In the meantime, the Evans Signal Laboratories Sferics Section made simultaneous observations at Fort Monmouth. For the most part, the simultaneous runs were made when thunderstorm activity was occurring in the Midwest so that the large consistent bearing errors noted for Ramey and MacDill might be examined. It was felt that departures of the indicated bearings from the true bearings were functions of the following three sources of error:

(1) Site

(2) Instrumental uncertainties

(3) Guiding effect of mountainous terrain

By making simultaneous observations at the local site and comparing the azimuths of flashes derived from the spare and the station sets, the magnitude of inherent instrumental errors could be determined. By making simultaneous observations with the spare set at a remote site, the magnitude of site errors could be determined. Thus, by the process of elimination the guiding effect theory could be evaluated.

Figures 162, 163, and 164 show the smoothed error curves for sites 1, 2, and 3, respectively, at Ramey. Site 1 is beside the local station, and sites 2 and 3, the remote locations, approximately two to three miles distant from the local site. In each case a sinusoidal error curve with a period of 180° of azimuth was clearly indicated. Because of the symmetry of the error curves, there is little doubt but what the inherent instrumental errors are the important components of the overall consistent bearing errors of the AN/GRD-1A. Site and the proposed guiding errors must play a negligible role. Investigations by the Sferics Section at Evans Signal Laboratories utilizing simultaneous runs between the Air Weather Service station and a mobile station revealed a similar sinusoidal character to the error curve. It was their conclusion, also, that the consistent bearing errors noted during the evaluation project were caused by a condition existing within the AN/GRD-1A proper.

The following reasons have been suggested by Mr. Pick and Mr. Hixson of the Evans Signal Laboratories to explain the sinusoidal error curve:

(1) Improper orientation of loops.

(2) Improper tuning of loops with respect to amplifiers.

(3) Improper orientation of plates of cathode ray tube with respect to each other.

The last reason regarding the CRT may be ignored since calibration of the tube is performed periodically so as to correct for errors resulting from improper plate alignment. The first reason regarding improper loop orientation is a remote possibility for explaining the consistent bearing errors since the orientations, when carefully performed, are accurate to within seconds of a degree. The explanation of improper tuning of loops with respect to the amplifiers is by and large the most reasonable explanation for the sinusoidal error curves. Initial investigations by Mr. Hixson have revealed that deviations from the 45° line occur when the vertical and horizontal amplifiers are non-linear with respect to each other. A certain amount of non-linearity is to be expected as it is extremely unlikely that two amplifier circuits will produce identical voltage outputs for the same inputs. Hixson found larger deviations when the loops were tuned to different frequencies ($\pm\frac{1}{2}$ kc) than the amplifiers. These deviations were of the same order of magnitude as the error curves (Figures 162 and 164) at 45°. This explanation seems most reasonable, since it can explain the 180° shift in phase between the Ramey error curves from sites 1 and 3 (Figures 162 and 164). In one case, the loops were probably tuned to a higher frequency than the amplifiers; and in the other case, the loops were tuned to a lower frequency than the amplifiers. This explanation of loop and amplifier mistuning would, however, require that the error curves pass through 0°, 90°, 180°, and 270° exactly, since only one of the loops would be receiving a voltage at these azimuths, while the other is at a null point. The error curves from the Ramey sites do not exhibit these characteristics precisely, so that there are undoubtedly other factors at work, besides the loop and amplifier mistuning. The error curve for the Ramey site 2 (Figure 163) shows errors of much greater amplitude than those of sites 1 and 3. Site 2 was located at the Ionospheric station and consequently local interference was substantial thereby causing an accentuation of the error curve.

Figure 165 shows the error curve for the Kindley site. This curve does not exhibit the sinusoidal feature as strikingly as the Ramey or Fort Monmouth curves. The MacDill data are not presented since they were insufficient to permit a complete investigation of 180° of the compass rose.

Another result of Hixson's work is the fact that signal strength appears generally to be inversely related to the magnitude of errors

in azimuth. This would explain, in part, the large discrepancies noted in the Ramey bearings when the storm area was in the Far Mid-west.

5. Called-Flashes Versus Fixes

During the analysis of a sferics run, the procedure adopted was that of having one designated station "call" by time every flash on its film with the other four stations synchronizing on the same time groups. Since we were interested primarily in fixes occurring over continental U. S. for the direct association of fixes with thunder-storms, the calling station was, in all cases, one of the three located within the U. S.; i.e., Robins, MacDill, or Fort Monmouth. In the majority of the runs, Robins was designated as the calling station.

For the ten runs analyzed, the average percentage of called-flashes which resulted in fixes was 35%, although the percentages for individual runs ranged from 22 to 78%. The statistics for each two-minute run are tabulated below.

DATE-TIME		NO. OF FIXES	ESTABLISHMENT OF CALLED-FLASHES	% FIXES/ FLASHES
060730Z	July 1951	313	1440	22%
061330Z	July 1951	453	1200	38%
061530Z	July 1951	407	1080	38%
070630Z	July 1951	303	840	36%
071430Z	July 1951	329	480	70%
091130Z	July 1951	595	1320	45%
111330Z	July 1951	284	720	39%
200030Z	July 1951	592	1920	31%
200630Z	July 1951	306	480	64%
201830Z	July 1951	748	960	78%
Averages		433	1054	35%

The question which follows naturally from a glance at the above percentage figures is: Why do not all called-flashes result in fixes? No systematic association with time of day was found, nor any association with geographic location of the major concentration of fixes. Although substantiating data are not available, the following are the most probable reasons for the occurrence of flashes not resulting in fixes:

(1) Flashes detected only by the calling station may be nearby weak discharges from cloud-to-cloud, cloud-to-air, or within the cloud itself. The powerful earth-to-cloud (return) discharge is generally considered to be the only flash with sufficient energy to transmit a ground pulse that can be detected by at least three stations of a widely-spaced net.

(2) Unusually weak earth-to-cloud discharges may occur which are detected by only the calling station and perhaps one other station.

(3) The origin of the discharges may be too distant for detection by at least three stations.

(4) Occasional drift in the electro-mechanical timing units may cause inaccurate time synchronism on some of the called-flashes.

(5) Elliptical flashes occur occasionally on the film introducing considerable uncertainty in the reading of the azimuths. These flashes are the result of either nearby discharges overdriving the amplifier circuits or of ground and sky-wave phase interference.

(6) Although the sferics stations in the Caribbean net are sharply tuned to 10 kc/sec, there are some indications that this may not be the optimum frequency for the detection of sferics and that the detectable power of discharges varies in frequency from one flash to another.

(7) Inherent instrumental errors and the parallel beam uncertainty.

PART IX

COMPARATIVE COST ANALYSIS

A monthly cost analysis was prepared for Type A, R, Z and Y sections for comparative purposes. A tabulation of this analysis follows:

TYPE STATION	A	R	Z	Y
Initial Equipment Outlay	$51,283	$57,106	$22,658	$24,820
Personnel/mo.	4,598	1,549	2,120	2,369
Supplies/mo.	419	8,396	400	525
Personnel and Supplies	5,017	9,945	2,520	2,894
No. of Observations/mo.	720	120	120	120
			---3Z+1Y---	
Cost/observation	7	83	87	

Although the data derived from each type section may not be

directly compared, a comparison might be made of the numbers of each type station required to furnish an end product covering a specific area. The sferics net normally consists of one Y and three Z sections, and sferics data derived from this net cover an area enclosed by the Sferics Plotting Chart (AWS-WPC 9-18A). The cost per sferics observation is $87, and this figure includes the operation of the four stations. In order to obtain an end product from R-section data over a comparable area, a reasonable estimate is that thirty type R stations would be required at a total cost of $2,490 per network observation. A conservative estimate of the number of type A stations which would be required to give adequate surface synoptic coverage of the area in question is 500 at a total cost of $3,500 per network observation. These figures are not intended, by any means, to show that sferics observations should replace R- or A-station observations, but merely to show that sferics observations are relatively inexpensive.

PART X

SUMMARY OF CONCLUSIONS

Preliminary investigations (Part II) revealed (1) that the monthly distributions of sferics fixes over a two year period followed generally the same patterns of the normal monthly distributions of thunderstorm days derived from the forty-year record of Alexander, (2) that the effects of magnetic storm activity on the propagation of sferics indicate a tendency toward an inverse relationship (correlation coefficient of -.212), (3) that the effects of magnetic storm activity on the directional characteristics of sferics indicate also a tendency toward an inverse relationship (correlation coefficient of -.344), (4) that a diurnal variation in the number of fixes exists with a minimum at 1200Z and a maximum at 0000Z, and (5) that July exhibits a maximum (6550) of sferics fixes and January a minimum (5350), while variations from month to month do not appear to be significantly systematic.

The origin of a sferics fix is an electromagnetic disturbance associated with a lightning discharge. This conclusion was based upon a direct association of sferics fixes with reports of thunderstorms derived from a dense network of special observers (Part III). Complete analyses (every discernible flash) of selected two-minute runs during July 1951 were utilized in this investigation.

Because of the prohibitive time consuming feature of a complete flash analysis, various samples were evaluated for adequacy (Part V). The 250-flash sample was selected from the three samples examined as offering the greatest detection (60%) at a reasonable cost of time (2½ hours).

An independent check of the adequacy of the 250-flash sample was made utilizing additional runs during July, 1951, in a direct association of sferics fixes and reports of thunderstorms (Part VI). In all cases, the 250-flash sample was determined to be representative.

The association of sferics fixes with characteristic synoptic patterns was discussed in some detail in Parts IV (complete flash analyses) and VII (250-flash sample). Certain facts and rules derived from these investigations on the utilization of sferics data over the area scanned in the absence of much or all the normal synoptic data are summarized below:

(1) Sferics data for March through September are generally abundant and the deduction of the causal synoptic patterns from these data is relatively simple. Little significance should be associated with isolated fixes which are generally local air mass disturbances.

(2) Sferics data for October through February are relatively less abundant, particularly north of approximately the 30th parallel, and the deduction process becomes more complex. Much significance must now be attached to the isolated fixes or small clusters in the northern latitudes, since these fixes are undoubtedly the result of frontal activity rather than local air mass thunderstorms. Continuity of sferics data is of utmost importance during this period, since a poor deduction of the causal synoptic pattern from a sferics map, isolated in time, is more likely to occur when the sferics data are relatively sparse. Subsequent maps will aid the analyst in substantiating or disproving his initial deduction.

(3) Bands of fixes with NW-SE orientation indicate warm frontal activity with the thunderstorms resulting from the forced ascent of warm moist air. The warm front should be placed parallel to and directly SW of the banded structure. The width of the band normal to the surface front is inversely related to the steepness of the frontal surface aloft. The length of the band along the surface front is directly related to the width of the southerly flow of warm moist air in the lower levels.

(4) Bands of fixes, predominantly loose in character, with a NE-SW orientation indicate cold frontal activity. Over land areas, the loose band will normally bracket the surface front with the thunderstorms being the result of frontal lifting directly in front of and behind the surface front. Scattered fixes or clusters may occur well behind the surface front as a result of instability thunderstorms within the cold air sector. Over water areas, the loose band will normally lie parallel to and behind the surface front as a result of frontal lifting and/or instability thunderstorms within the cold air sector. The frontal surface in

the lower levels has now assumed a more linear relationship with height and has become less steep over water areas so that the frontal lifting thunderstorms do not normally occur in advance of the surface front.

(5) Bands of fixes with an E-W orientation indicate quasi-stationary frontal activity oriented likewise through the center of the band. In the region of the band, cyclogenetic processes are taking place, generally in a pressure col.

(6) Blocks of fixes, i.e., bands with no preferred orientation, are indicative of cyclonic processes. These blocks may vary considerably in extent due in part to the seasonal variations of thunderstorm activity. Blocks of fixes have been noted occasionally in association with hurricanes, although accompanying sferics activity is erratic in orientation and in existence with respect to such disturbances.

(7) Particularly dense bands of fixes with a NE-SW orientation indicate pre-cold frontal squall line activity. Often a scatter of fixes behind the squall line band will indicate the position of the trailing cold front. As the squall line sferics activity decreases, the fixes along the cold front increase in number.

(8) The orientation of a band of fixes is indicative of the flow pattern aloft; a predominantly N-S orientation indicating meridional flow and an E-W orientation, zonal flow.

(9) The spatial distribution of bands, clusters, or blocks of fixes will indicate the positions of the troughs aloft, and the ridges may be accurately placed in the sferics null points. The amplitudes of the troughs may be deduced from the orientations of the sferics structures as in (8), above. For a hemispheric analysis where a "silent zone" exists, the sferics data in this region would be valuable aids in placing the troughs and ridges so as to complete the global analysis accurately. Wave-length forecasting techniques may then be applied with a greater degree of confidence.

(10) The production of a band of sferics fixes requires generally a warm tongue of moist air in the lower levels, perhaps up to 700 mb, overrun at right angles in the three dimensional picture by a cold dry tongue aloft. The isotach analysis at upper levels would thus show the regions of maximum velocity to be west and north of the sferics bands.

(11) Bands of fixes, occasionally loose in character, delineate easterly wave activity in the Caribbean area. Generally, the first in a series of waves exhibits the most intense activity with progressively reduced activity attending the subsequent waves.

(12) Not to be overlooked are the severe and hazardous weather phenomena occurring within the sferics structures themselves, and in close proximity to them.

Discussions regarding the radio direction finding errors inherent in the sferics equipment and the errors resulting from the parallel beam uncertainties are included in Part VIII. The primary cause of errors in the present equipment appears to be the non-linearity of the amplifiers with respect to each other. The magnitudes of the errors are accentuated when the loops are tuned to a different frequency than the amplifiers. The nature of the error curve is sinusoidal.

A comparative cost analysis was presented in Part IX wherein type A, R, Z, and Y sections were compared. The cost per observation derived from a four-station sferics net (3Z + 1Y) is $87 as compared to $83 for each R section observation. The cost per observation for an A section is $7. Although the data may not be compared directly, the area scanned by the sferics net is enormous in comparison to the relatively local nature of R and A section observations. In this respect the cost of operating a sferics net is considered to be negligible in comparison to network costs for R and A sections to cover a comparable area.

Because of the convenience of obtaining verification data, and because of the scope of the Caribbean net, this report of the Sferics Evaluation Project has dealt solely with an evaluation of sferics data over the eastern United States, the Caribbean, and the western Atlantic areas. For any future operations in other areas, studies of this nature will be required with particular emphasis on the association between sferics fixes and synoptic patterns. Very little appears in the literature regarding the synoptic climatology of thunderstorm activity in relation to frontal patterns.

The problem of gaining data from relatively "silent zones" is normally approached through expensive reconnaissance flights and equally expensive ship reports. The utilization of sferics data provides a valuable adjunct or supplement to these reports at bargain basement prices.

APPENDIX I

PROJECT PERSONNEL

1. Officers:

		Date of Assignment	Approximate Duty Time With Project
Major Gard Oliveros	8219	15 Feb '51	2 mos.
Captain James W. Green	8219	19 Feb '51	6 mos.
Captain Harold E. Grenard	8219	24 Apr '51	12 mos.
Captain Mack Siler, Jr.	8205	3 Jul '51	12 mos.
Captain Robert Turkisher	8219	29 Mar '51	11 mos.
Captain William G. Wells	8205	7 Feb '51	4 mos.

2. Airmen:

T/Sgt. William G. Smiley	30173	9 Feb '52	5 mos.
T/Sgt. B. J. Wall	25171	9 Jun '52	1 mo.
S/Sgt. Stanley Braverman	29351	24 Oct '51	6 mos.
S/Sgt. Jesse C. Carriker	29351	15 Jun '51	6 mos.
S/Sgt. Ben J. Giarraputo	25250	15 Jun '51	6 mos.
S/Sgt. Leland E. Glenn	25250	21 Mar '51	8 mos.
S/Sgt. Walter N. Leneau	25250	18 Mar '51	8 mos.
S/Sgt. Robert L. Smith	29351	28 Aug '51	3 mos.
A/1c James D. Cornett	25250	30 Jul '51	2 mos.
A/1c Charles F. Gillikin	30150	7 Dec '51	4 mos.
A/1c Robert E. Gove	25250	19 May '51	7 mos.
A/1c James Gurlen	25250	28 Feb '52	4 mos.
A/1c English G. Hammond	25250	1 Aug '51	2 mos.
A/1c James C. Kidd	25250	17 May '51	13 mos.
A/1c Alfred E. Pesto	25250	17 Aug '51	1 mo.
A/1c James M. Smith	29351	15 Feb '51	6 mos.
A/1c Murray T. Winton	25171	6 Apr '51	10 mos.
A/2c James C. Barbour	25250	1 Aug '51	2 mos.
A/2c Glen L. Fuller	25250	2 Aug '51	2 mos.
A/2c Willie P. Hardeman	29331	21 Jul '51	2 mos.
A/2c Anthony Vitale	25230	Apr '52	3 mos.
A/3c Sam R. Griffith	25250	2 Aug '51	1 mo.
A/3c Robert J. McNamara	25230	13 Feb '52	5 mos.
A/3c Donald S. Schmidt	25250	1 Aug '51	2 mos.

APPENDIX II

REFERENCES

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4. Jensen, C. E., "A Review of the Sferics Problem ", Weather Service Bulletin, No. 1, 1951, pp. 48-60.

5. [Jensen, C. E.], Air Weather Service Technical Report No. 105-87, March 1952.

6. Kessler, W. J., Zetrouer, W. F., Smith, S. E., and Hersperger, S. P., Final Report (USA Contr. No. W36-039-SC-38201), University of Florida, 1 April 1951, p. 12.

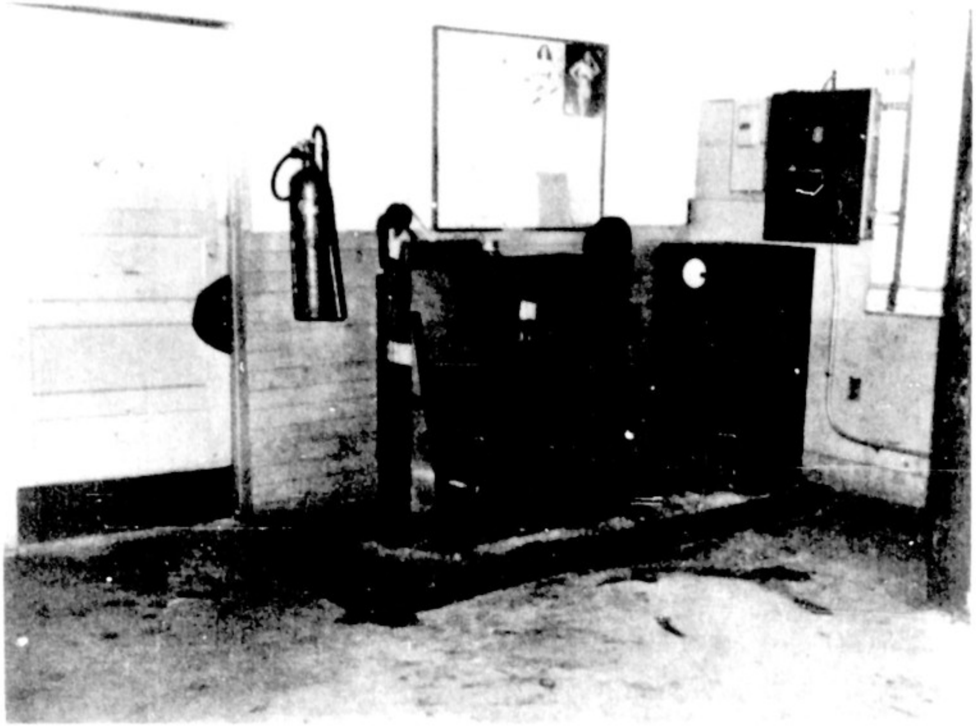


Fig. 1 Sferics Equipment at Robins

Fig. 2 Robins Project and Net Control Building

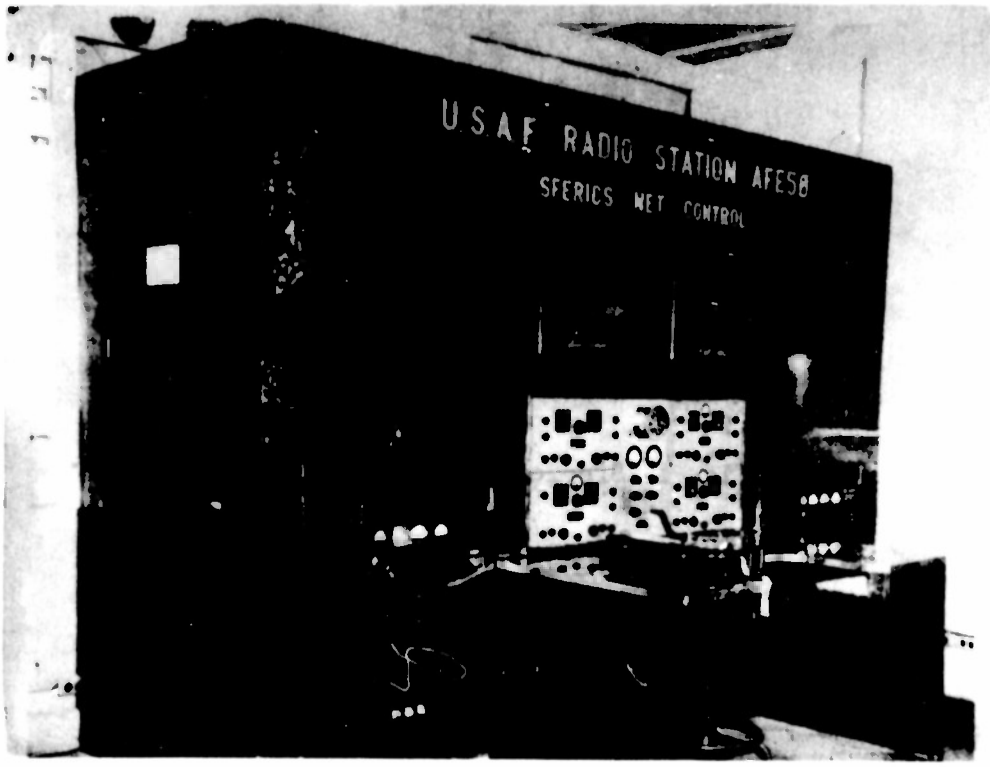


Fig. 3 Radar Communications Equipment
Robins Net Control Station

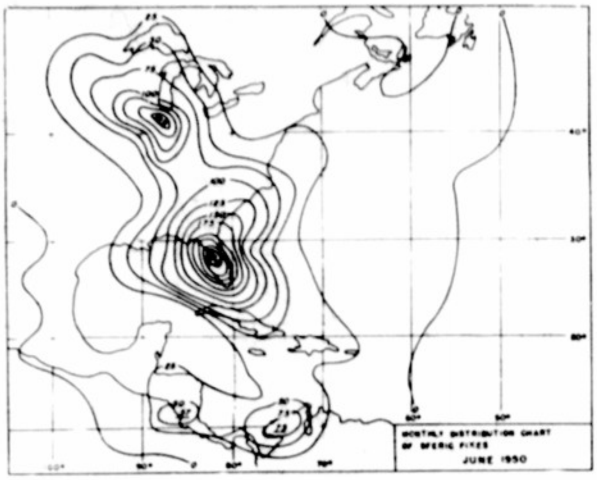
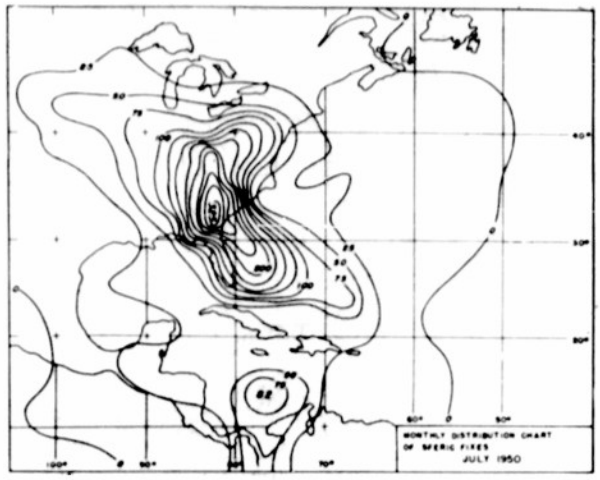


Fig. 4



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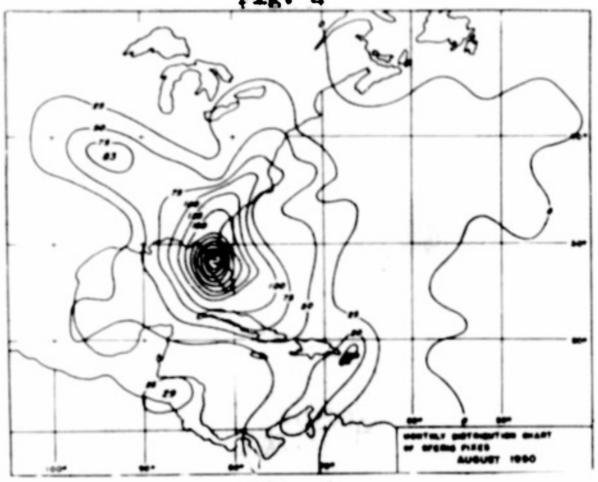

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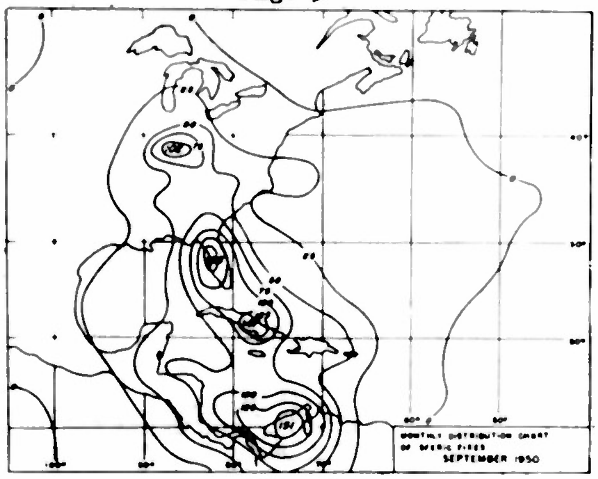

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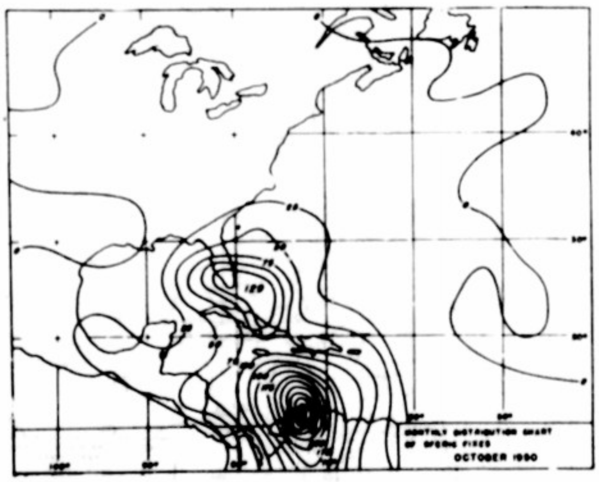
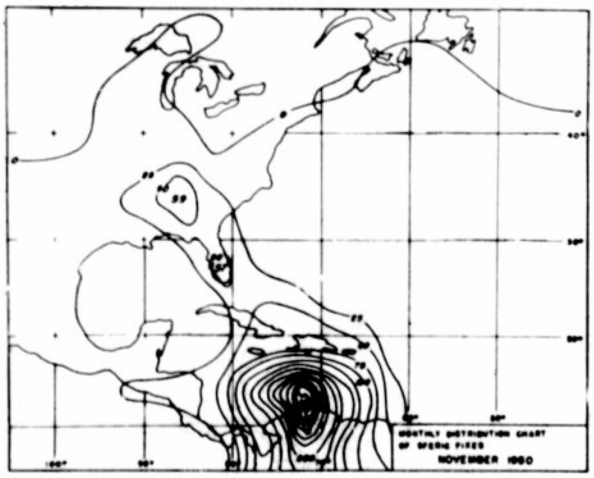


Fig. 8



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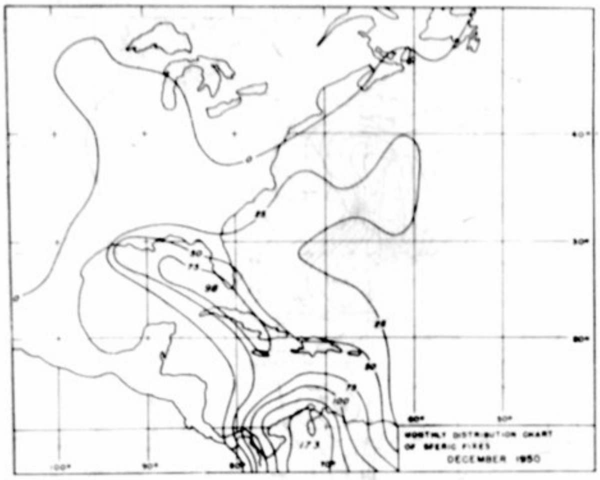

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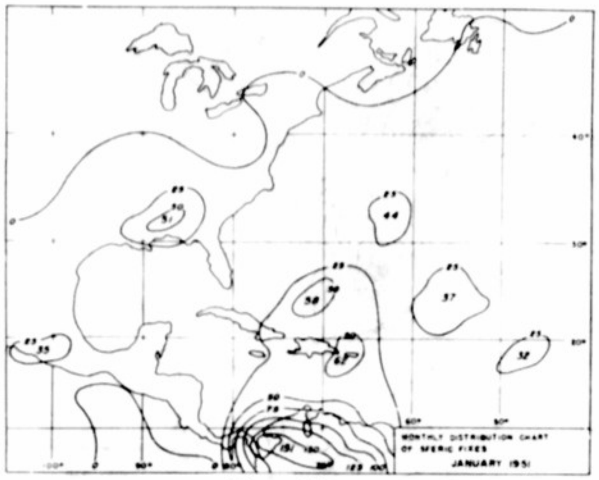


Fig. 11

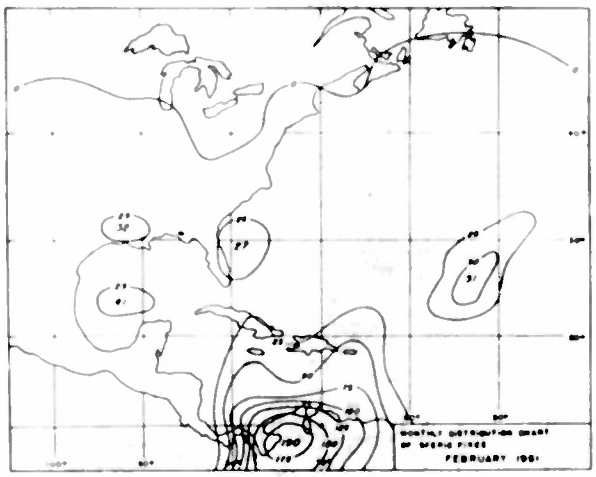
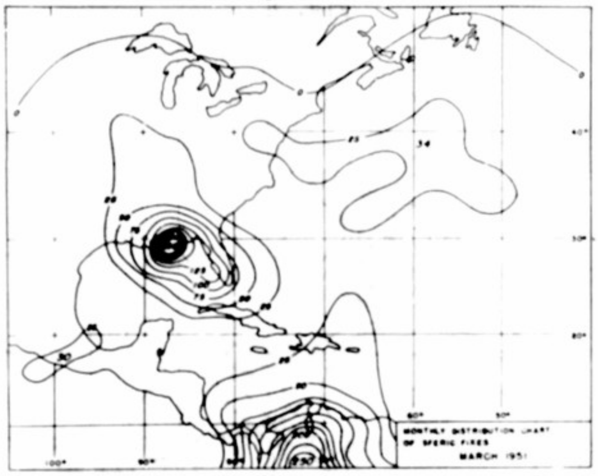


Fig. 12



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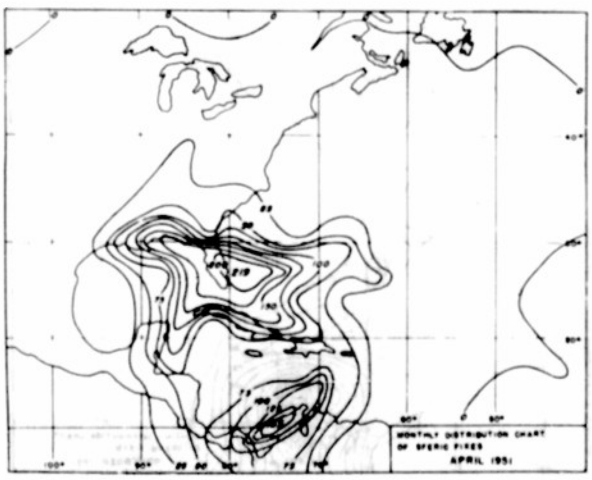

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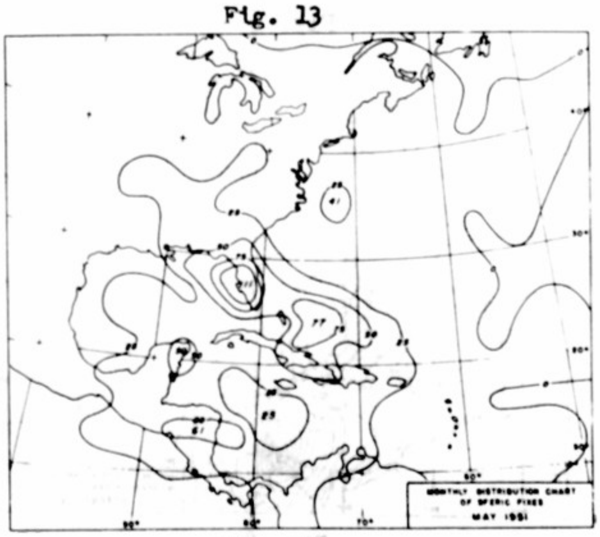

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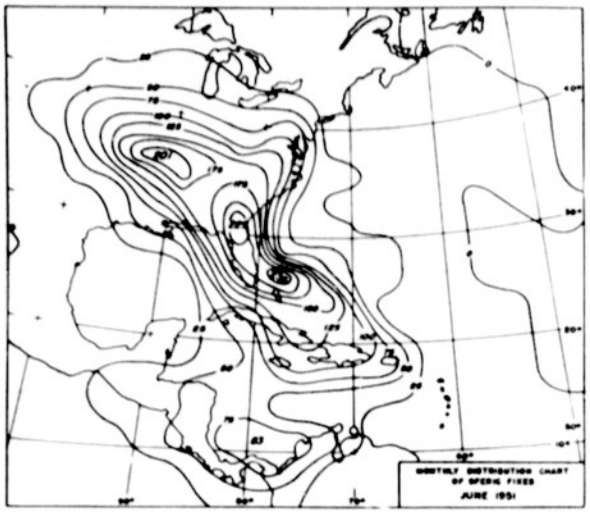

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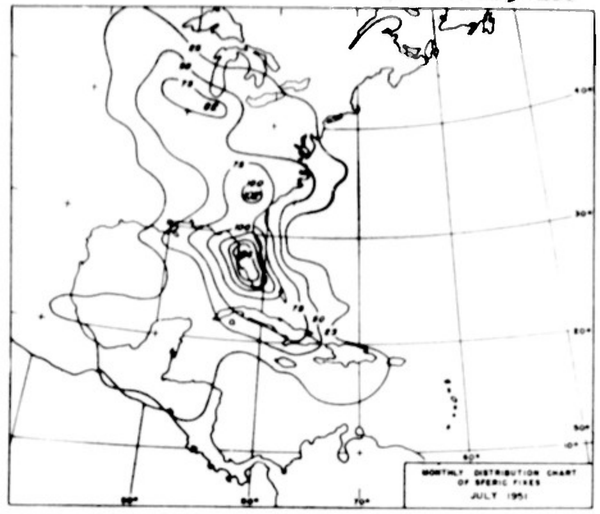

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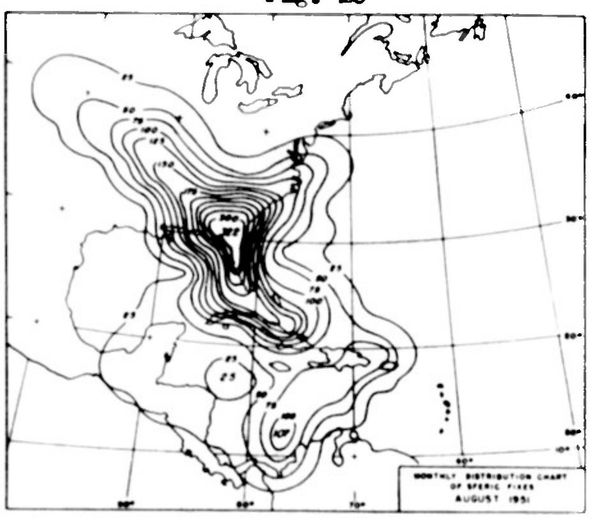

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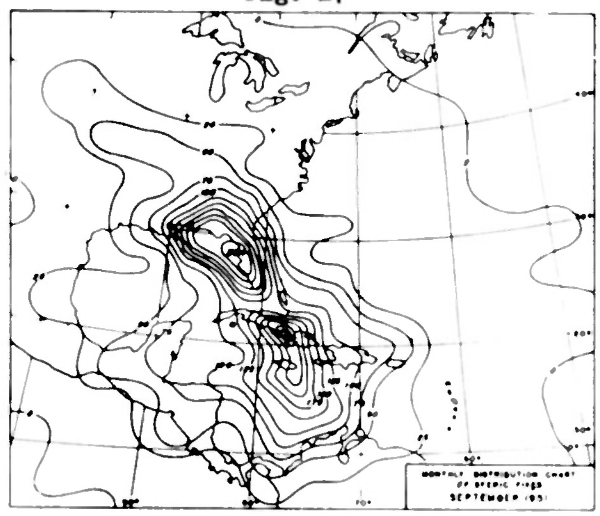

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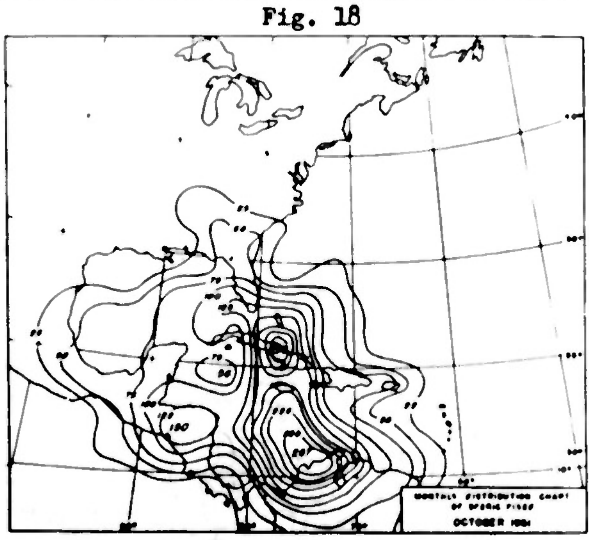

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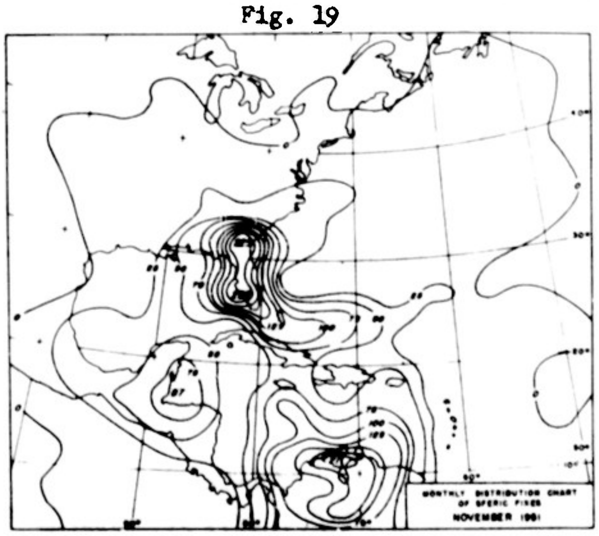

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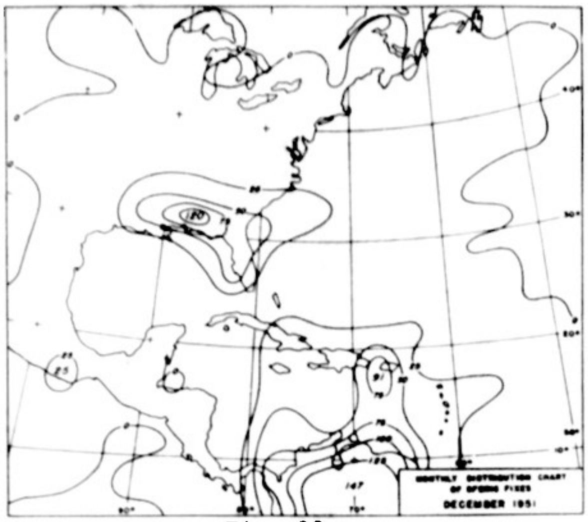

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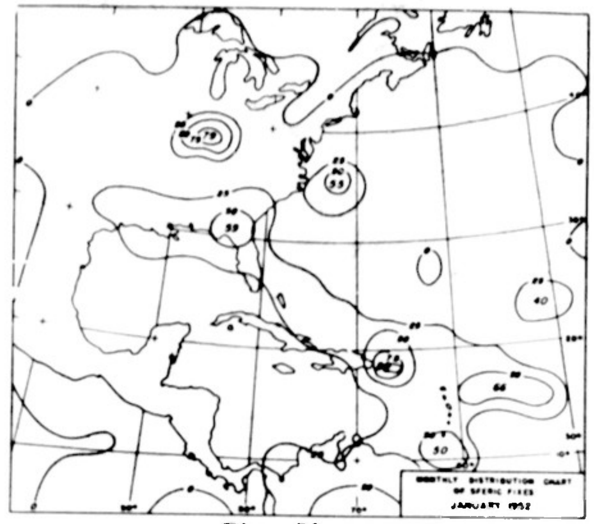

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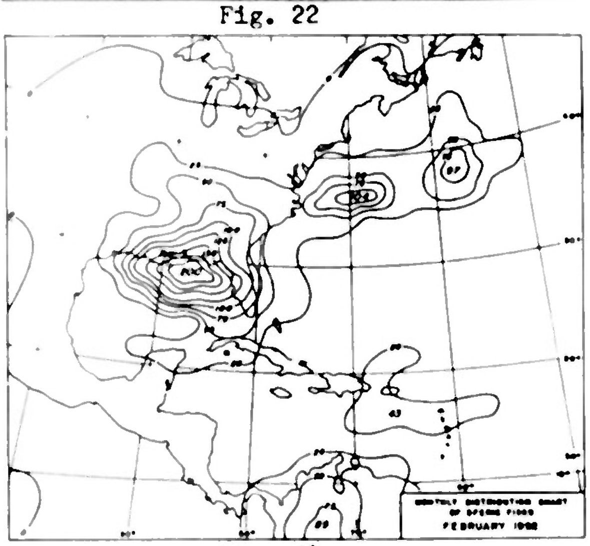

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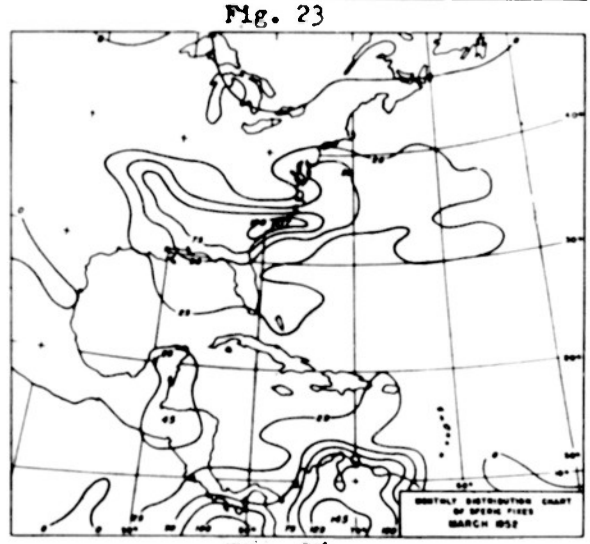

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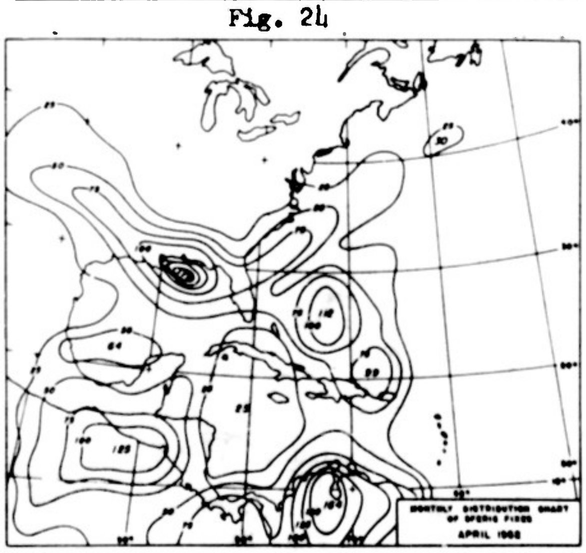

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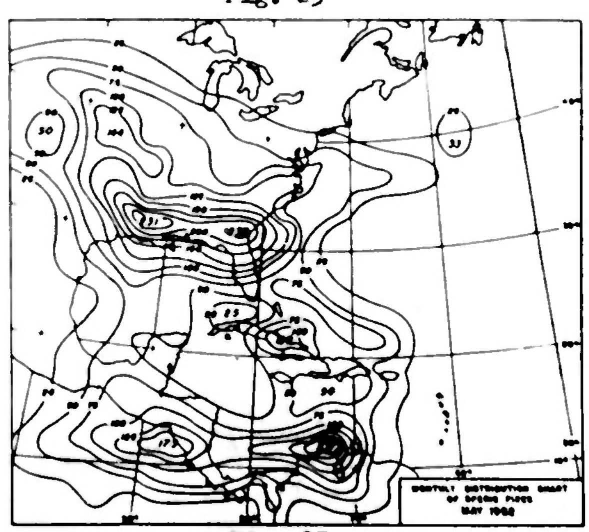

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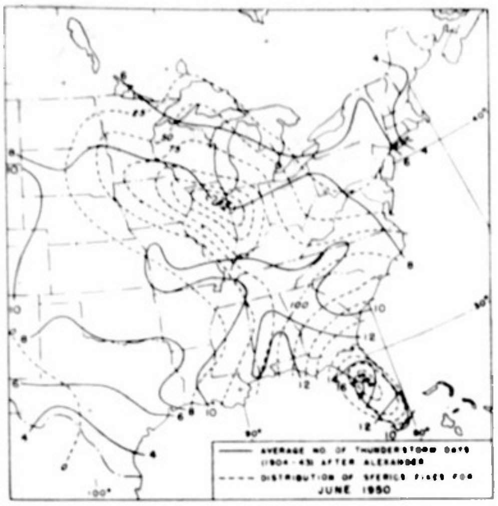

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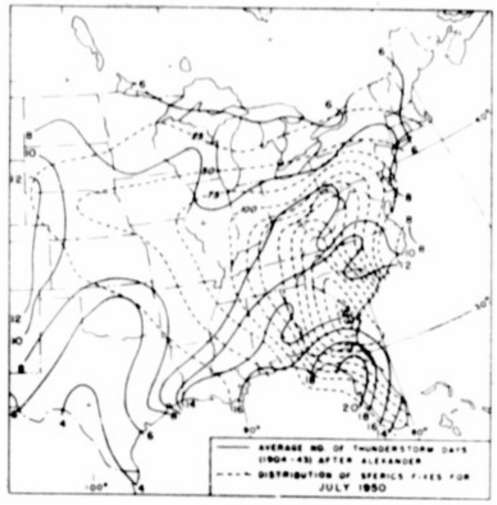

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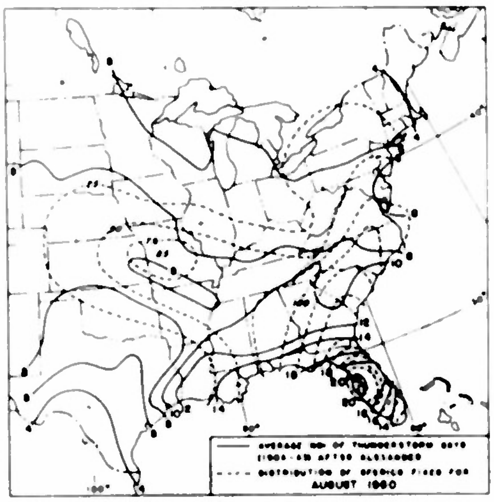

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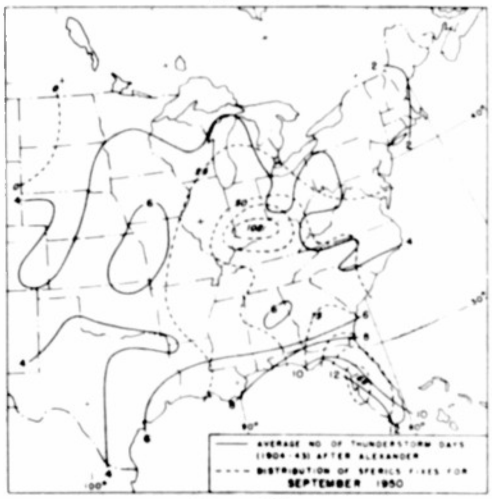

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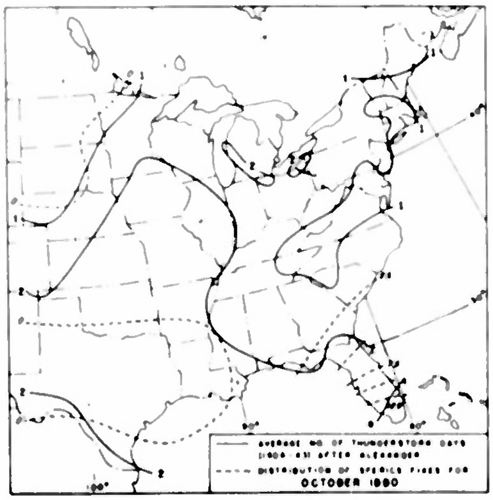

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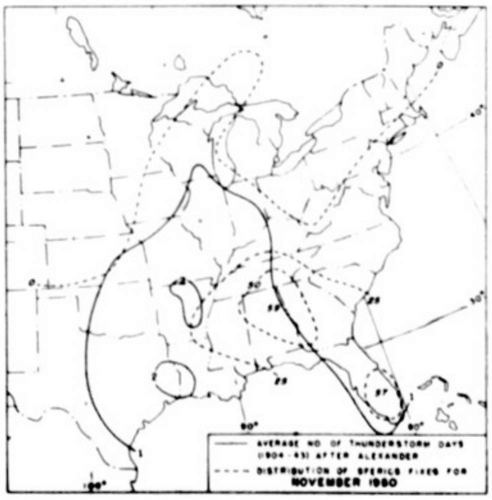

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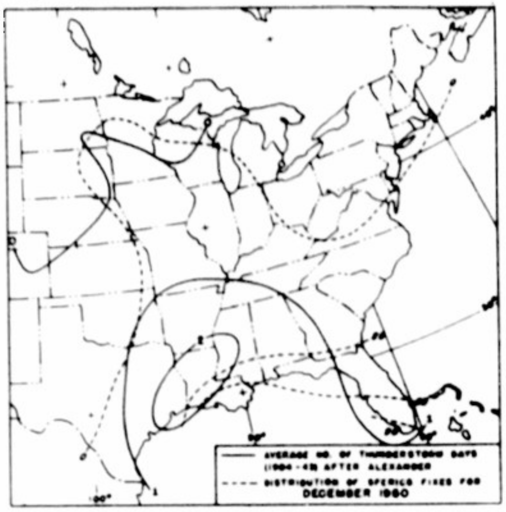

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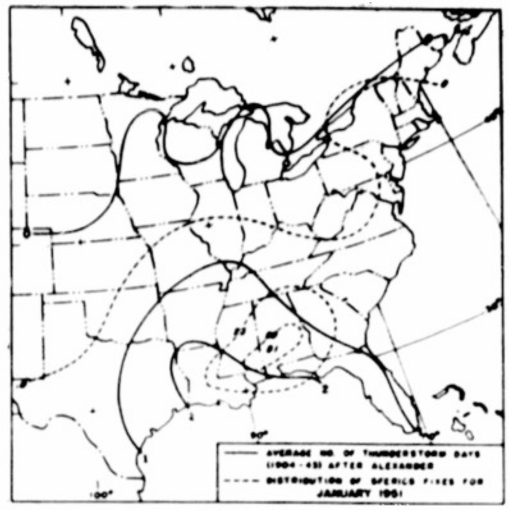

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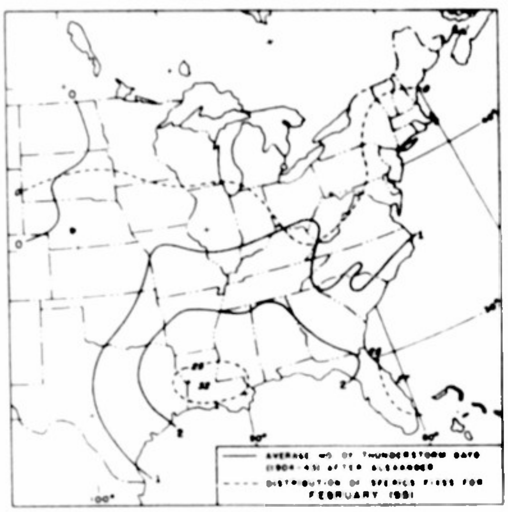

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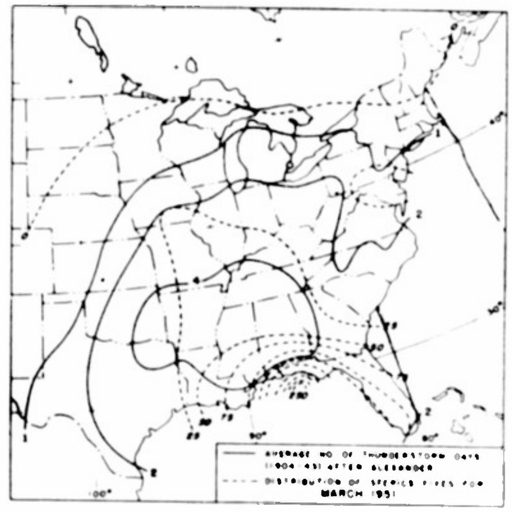

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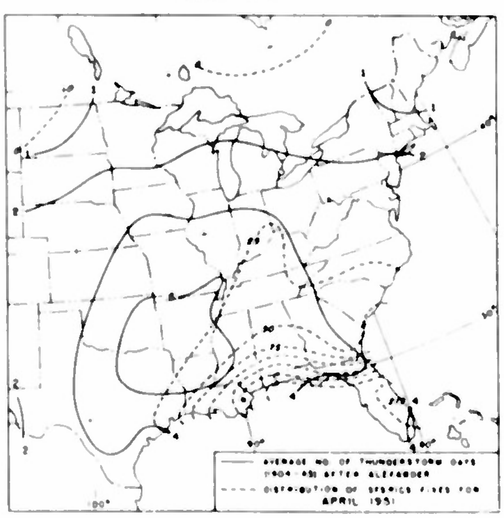

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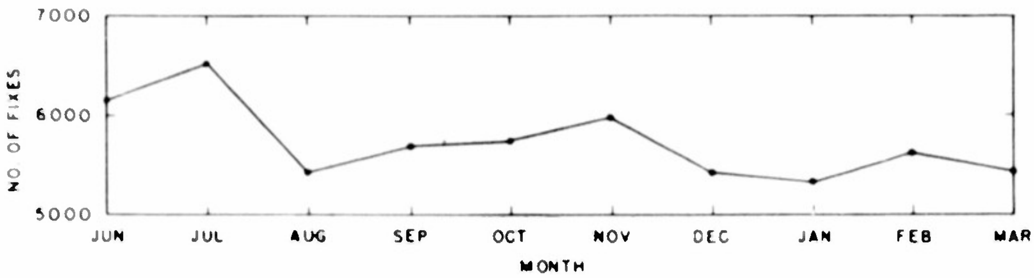


Fig. 39 Weighted Monthly Totals of Sferics Fixes

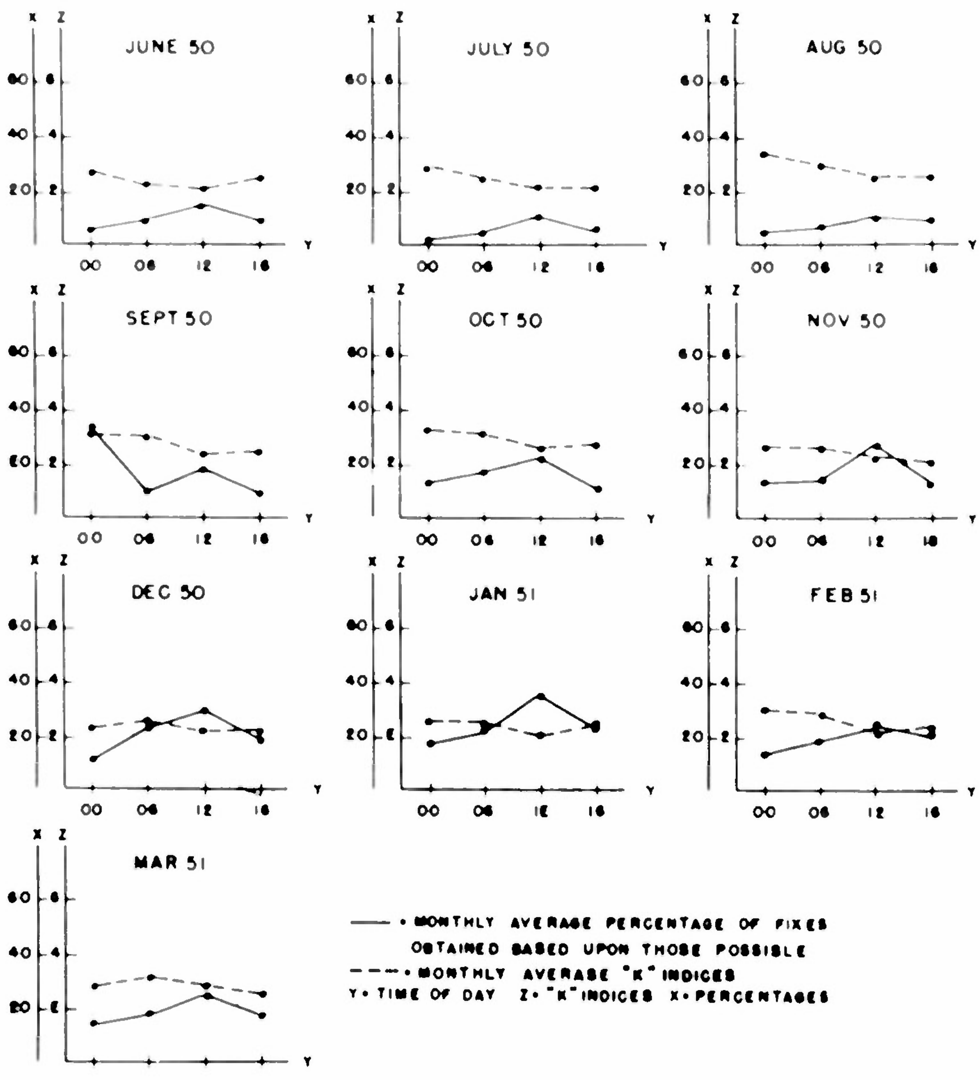


Fig. 40

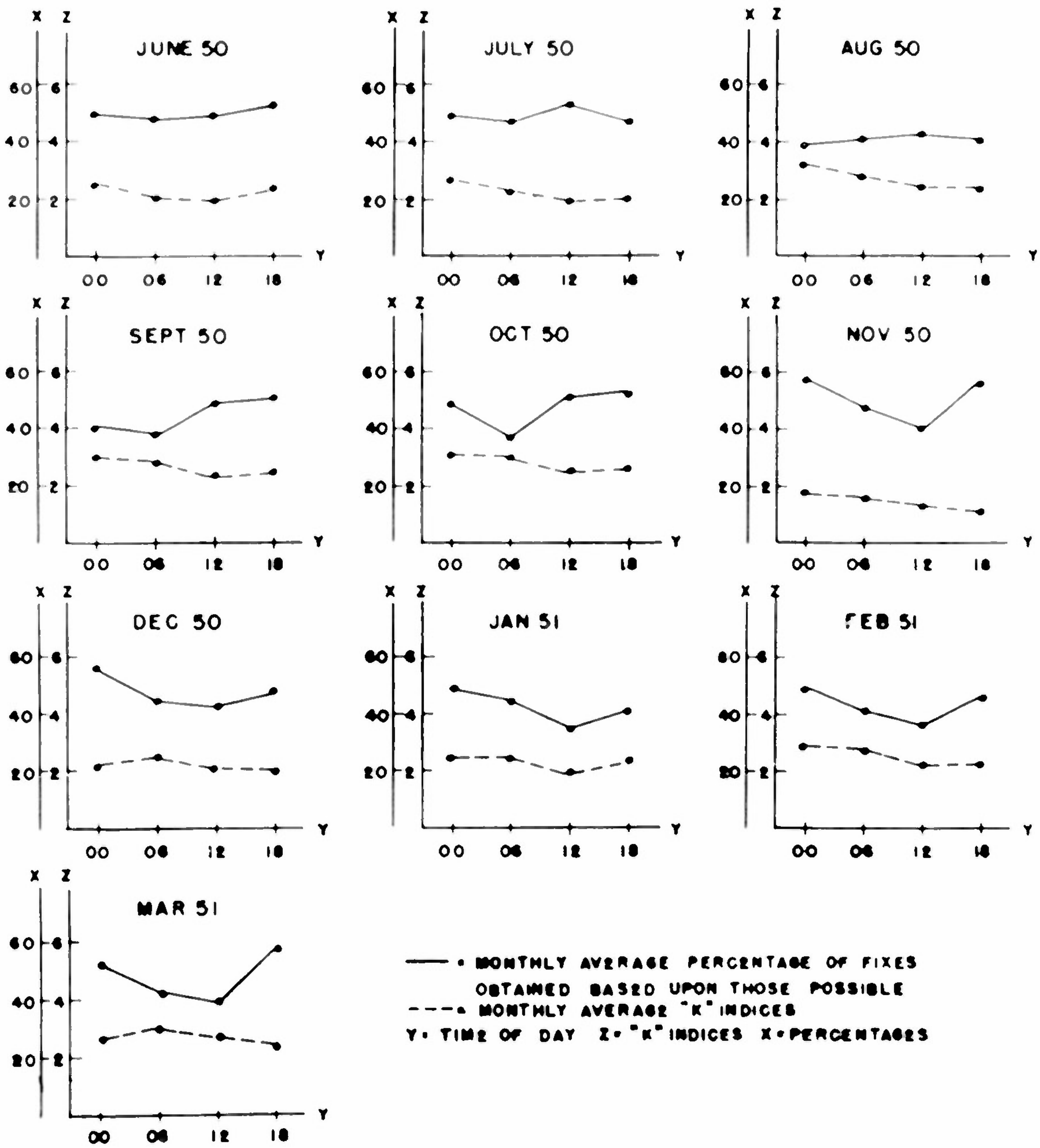

JUNE 50
JULY 50
AUG 50
SEPT 50
OCT 50
NOV 50
DEC 50
JAN 51
FEB 51
MAR 51
X
Z
Y
60
40
20
6
4
2
00
06
12
18
—— • MONTHLY AVERAGE PERCENTAGE OF FIXES OBTAINED BASED UPON THOSE POSSIBLE
- - - • MONTHLY AVERAGE "K" INDICES
Y• TIME OF DAY Z• "K" INDICES X•PERCENTAGES

Fig. 41

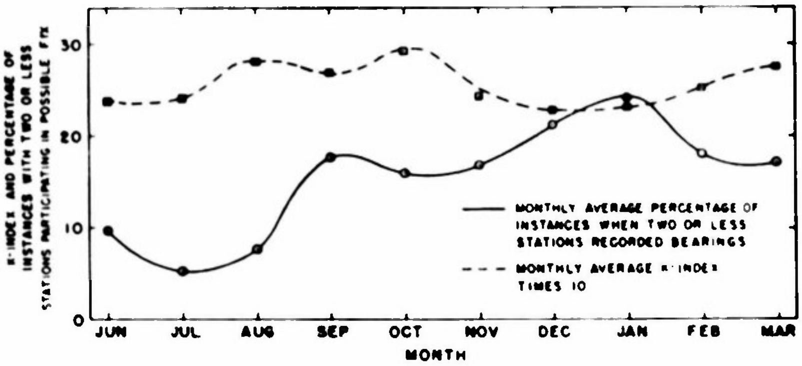


Fig. 42 Average K-Index and Percentage of Distances When Two or Less Stations Recorded Bearings Versus Month of Year

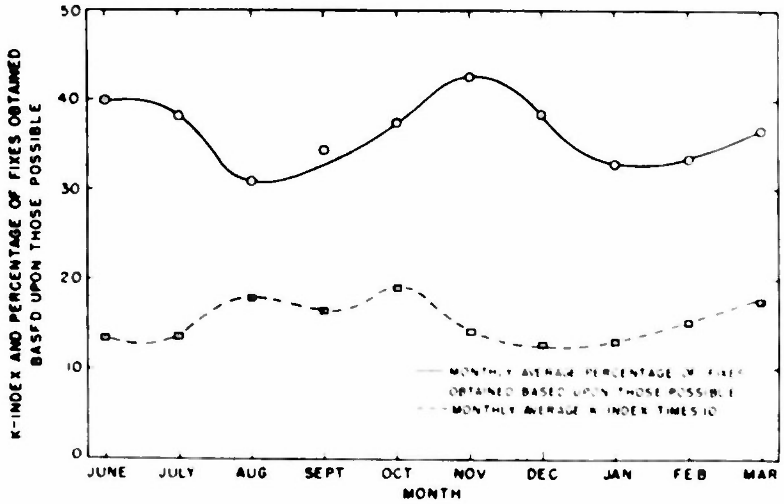


Fig. 43 Average K-Index and Percentage of Fixes Obtained Based Upon Those Possible Versus Month of Year

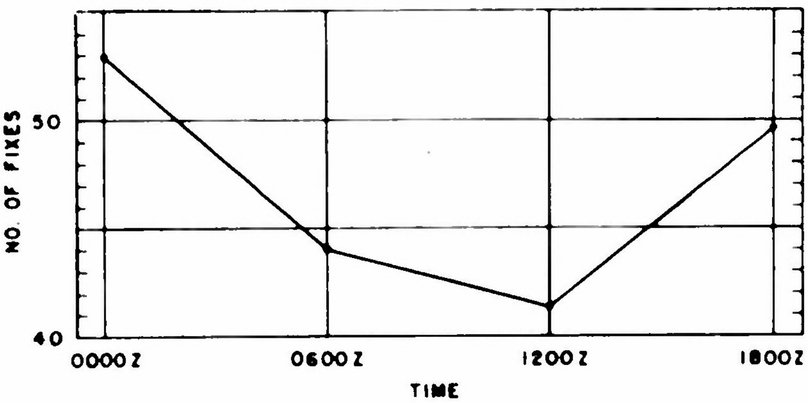


Fig. 44 Diurnal Variation of Sferics Fixes for the period, June 1950 - March 1951

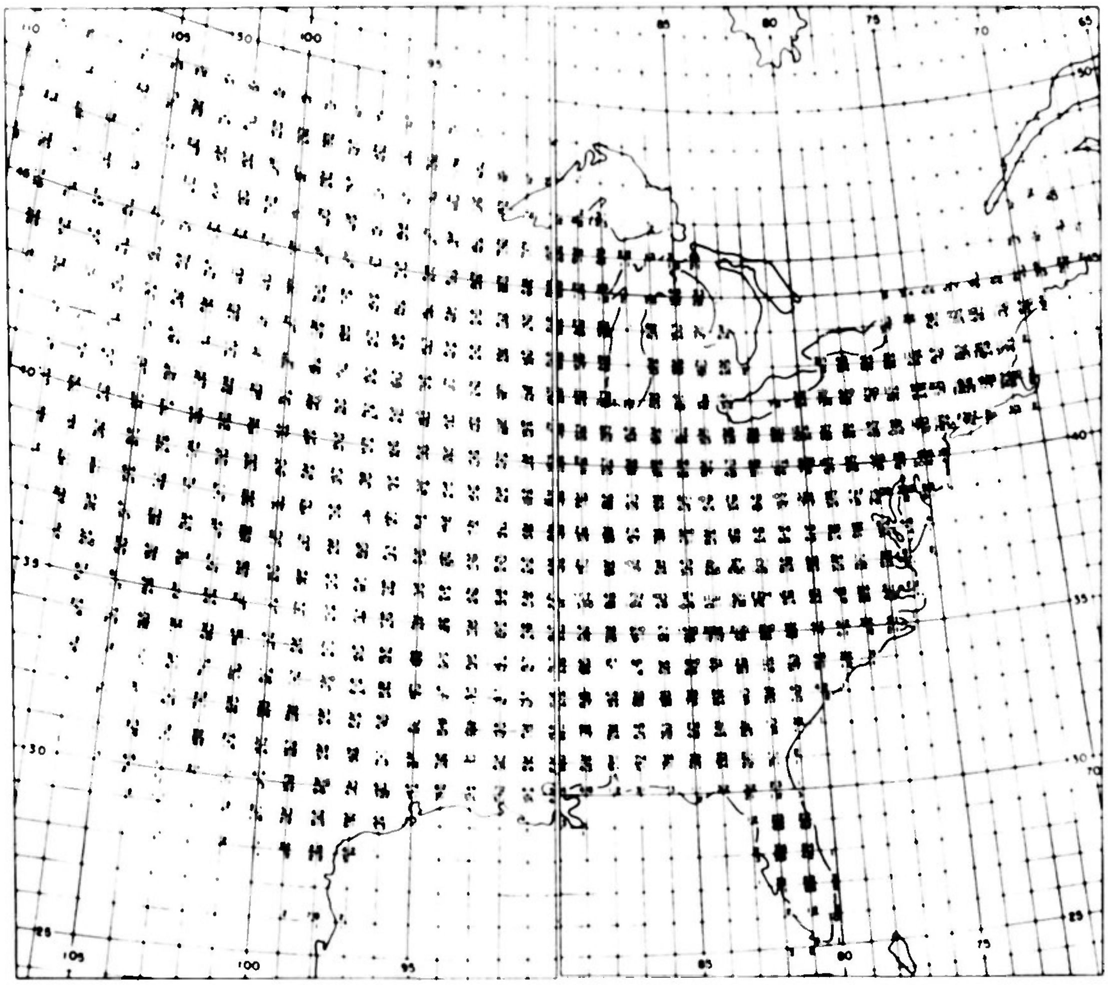


Fig. 45 July 1951 Observer Distribution Chart
Total Observers = 11,337

DEPARTMENT OF THE AIR FORCE

PENALTY FOR PRIVATE USE TO AVOID
PAYMENT OF POSTAGE, $300
(GPO)

OFFICIAL BUSINESS

Weather Detachment 6-26
Attn.: SFERICS Evaluation Project Officer
Robins Air Force Base, Georgia

AWS/SFERICS OP Form No. 1
(17 May 5.)

A. M.	YES	NO	P. M.	YES	NO
12:30			12:30		
1:30			1:30		
2:30			2:30		
3:30			3:30		
4:30			4:30		
5:30			5:30		
6:30			6:30		
7:30			7:30		
8:30			8:30		
9:30			9:30		
10:30			10:30		
11:30			11:30		

I saw lightning or heard thunder at the indicated time or within two minutes thereafter.
(*Please initial one: Yes or No*)

OBSERVER ....

PLACE ....

DATE OF OBSERVATIONS ....

EMPLOYER ....

CHECK TIME ZONE:

EDT ☐ EST ☐
CDT ☐ CST ☐
MDT ☐ MST ☐

16—64420-1 GPO

Fig. 46 Thunderstorm Data Card

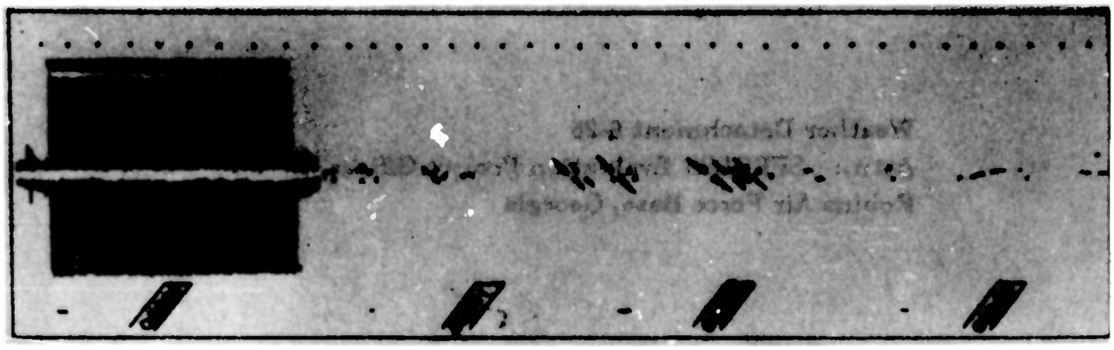


Fig. 47 Sample Film Record of Raw Data

Fig. 48 Sferics Film Viewer, Rapid Plotting

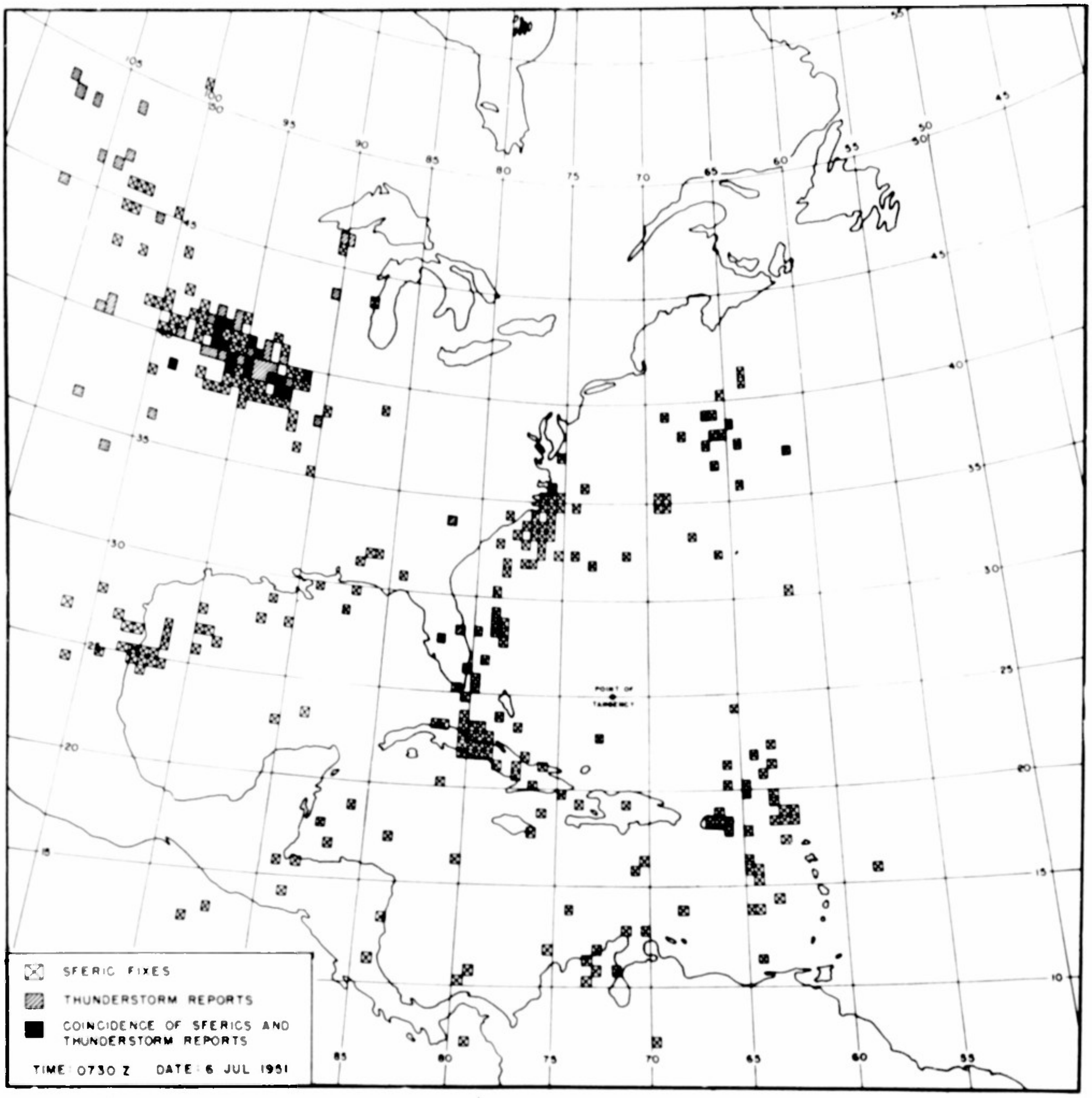

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 0730 Z DATE 6 JUL 1951
POINT OF TANGENCY

Fig. 49

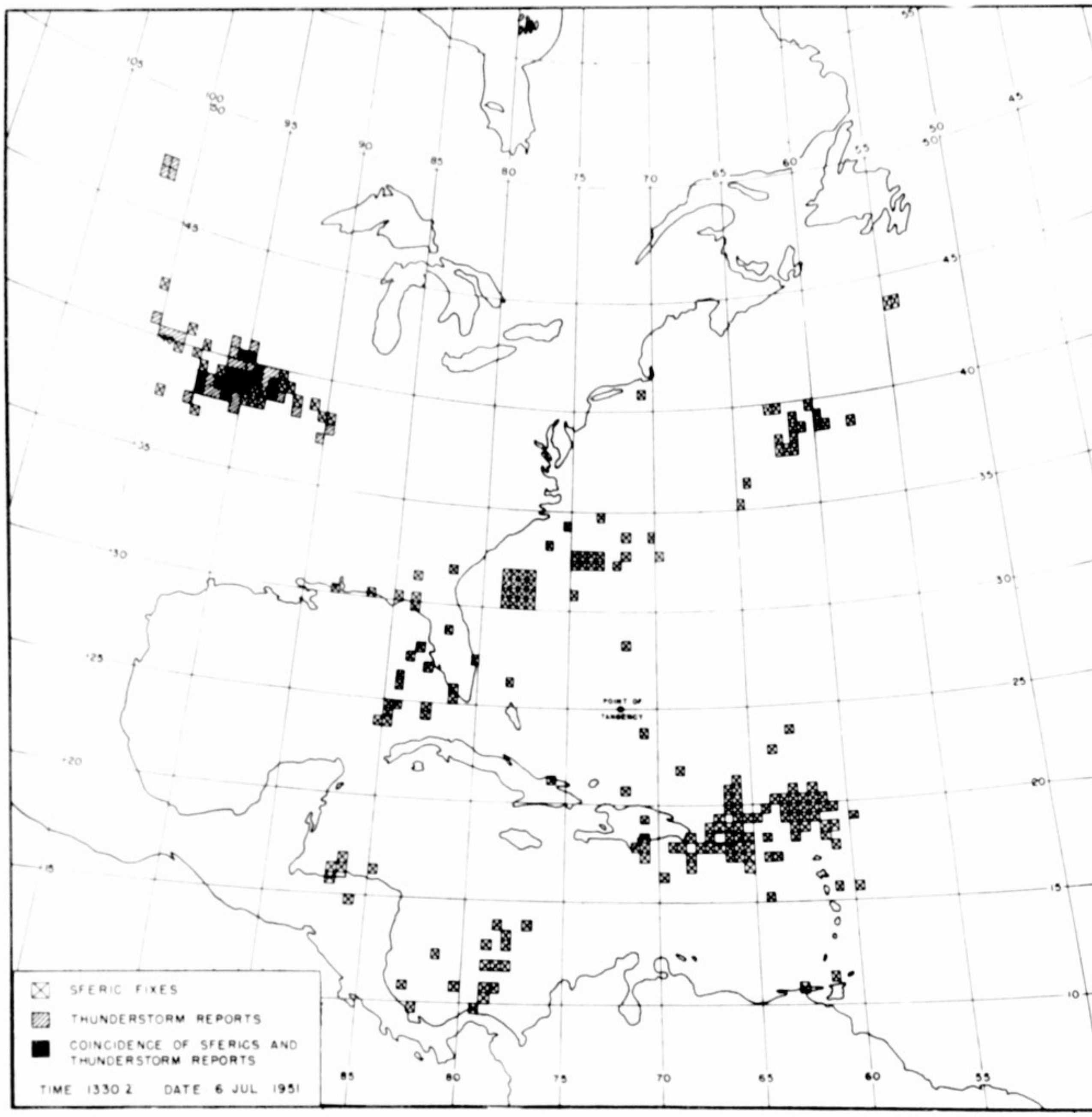

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 1330 Z DATE 6 JUL 1951
POINT OF TANGENCY

Fig. 50

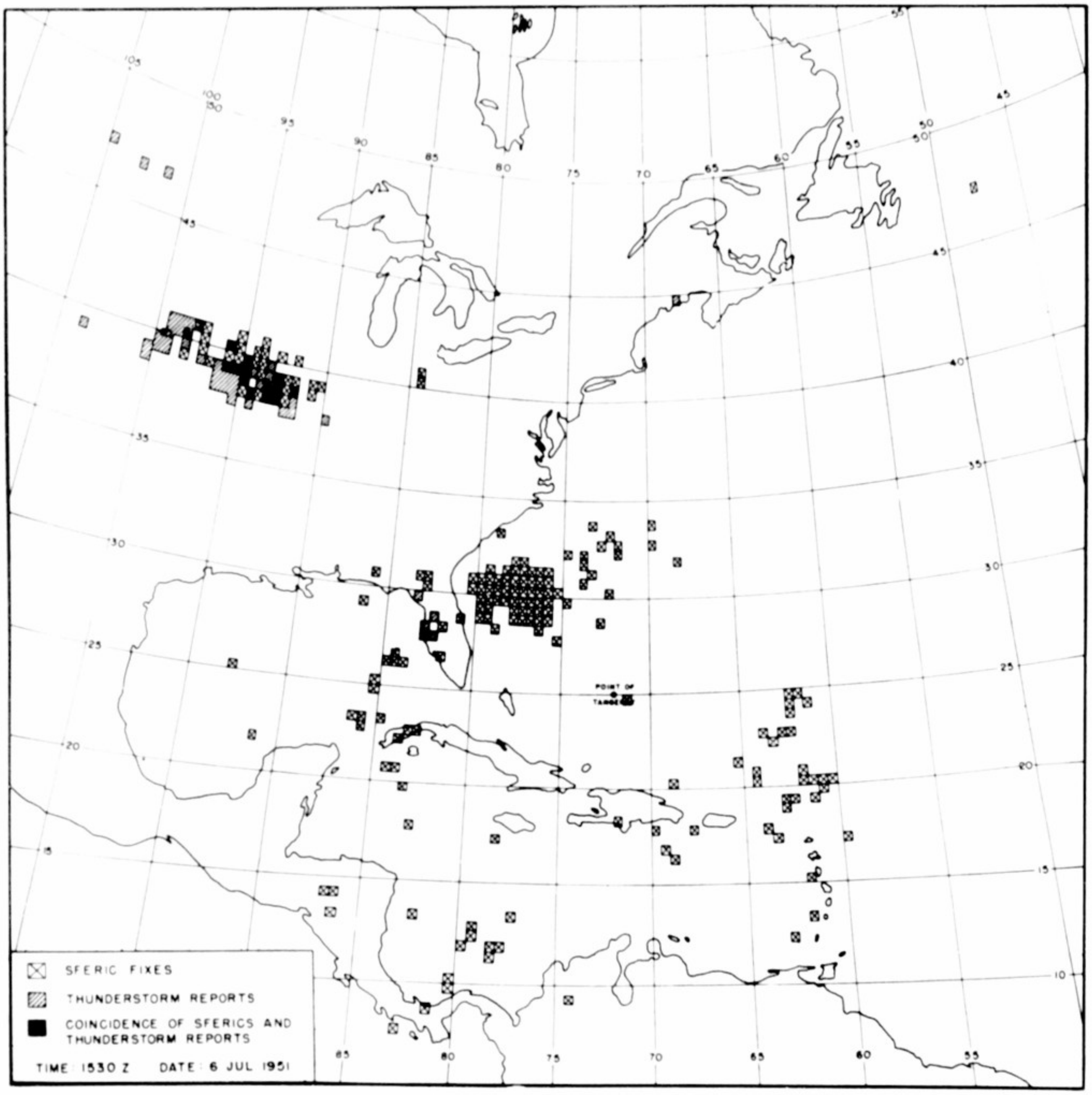
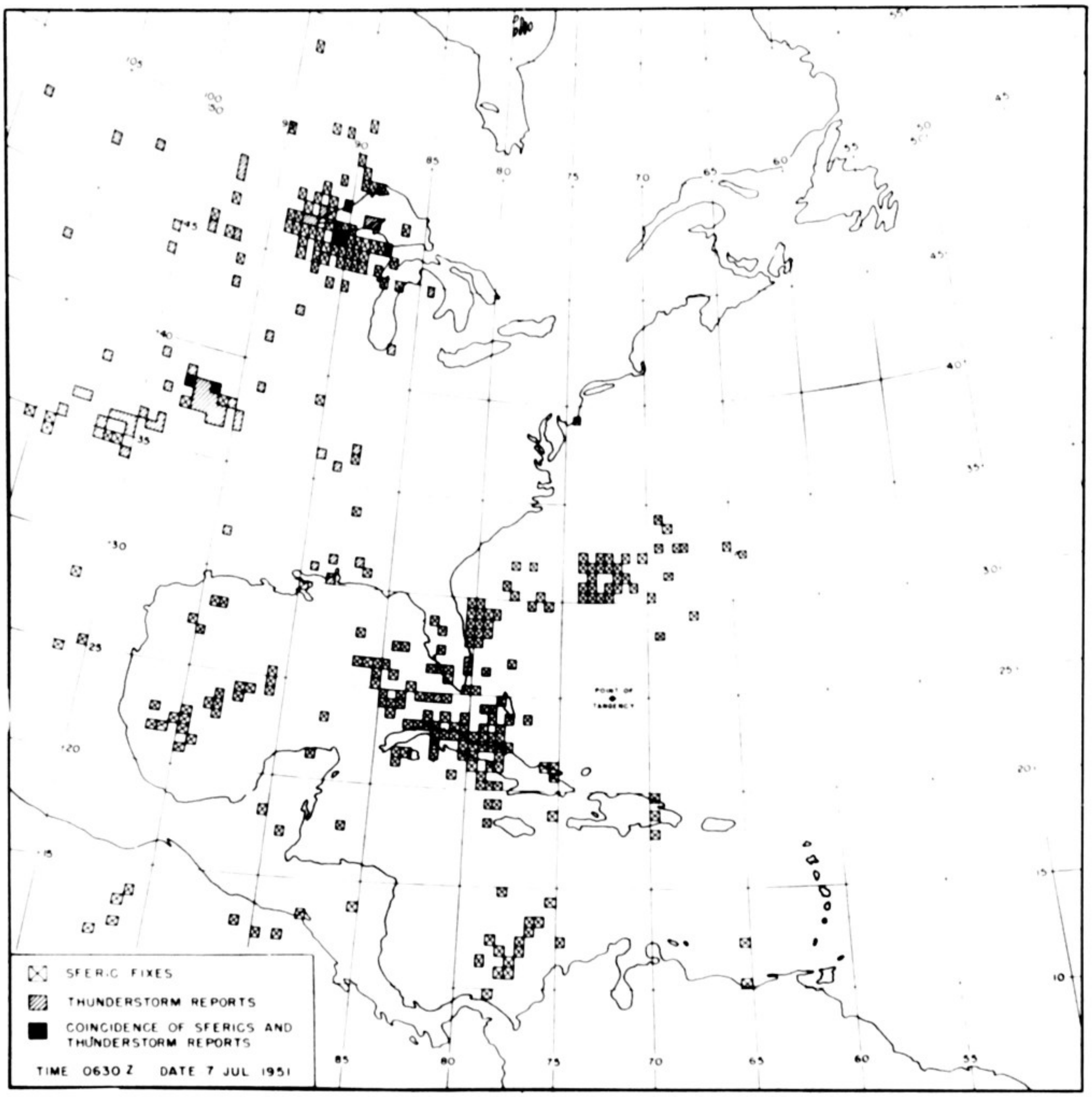
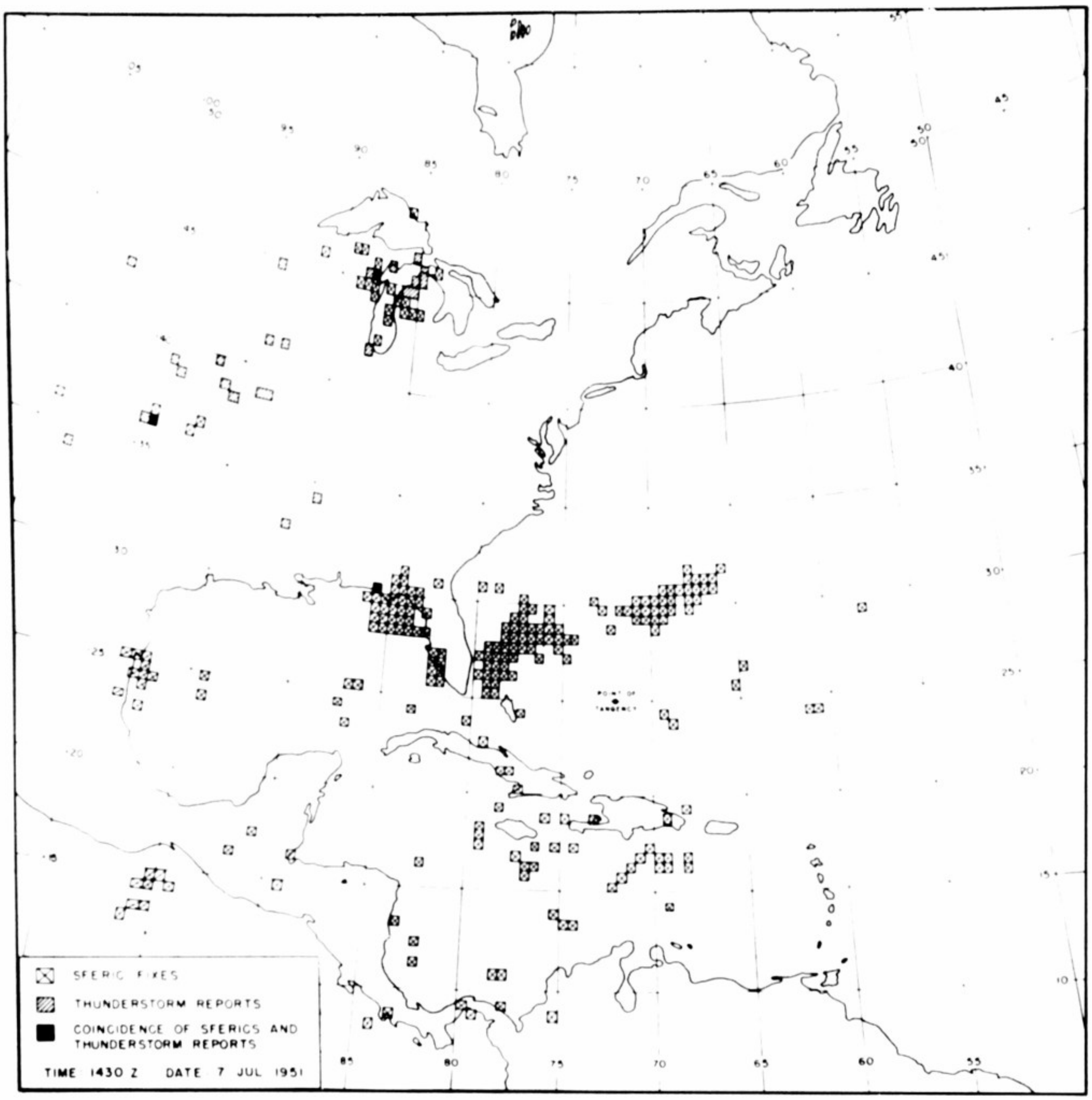

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME: 1530 Z DATE: 6 JUL 1951

Fig. 51



SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 0630 Z DATE 7 JUL 1951
POINT OF TANGENCY

Fig. 52



SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 1430 Z DATE 7 JUL 1951
POINT OF TANGENCY

Fig. 53

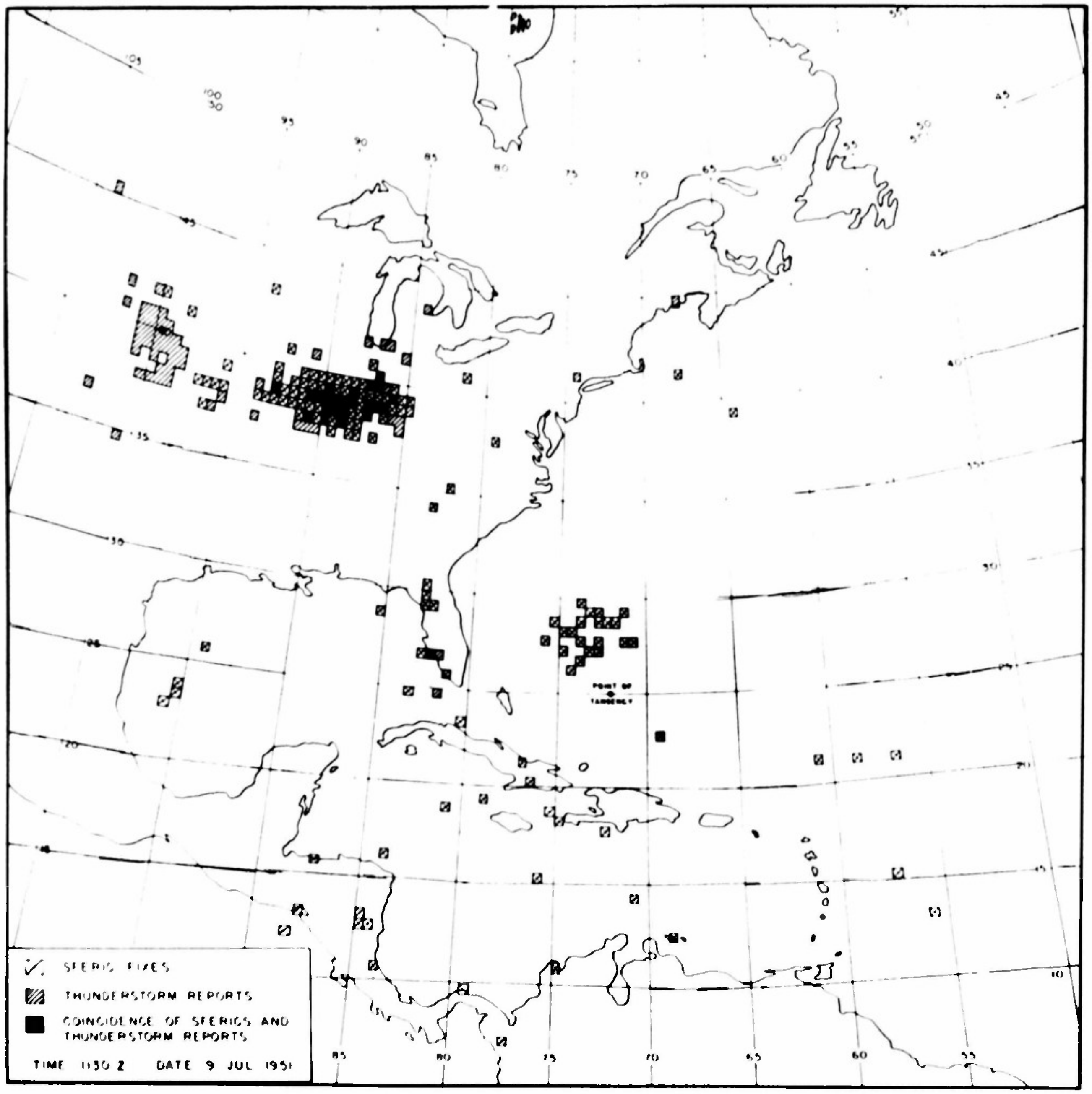

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 1130 Z DATE 9 JUL 1951
POINT OF TANGENCY

Fig. 54

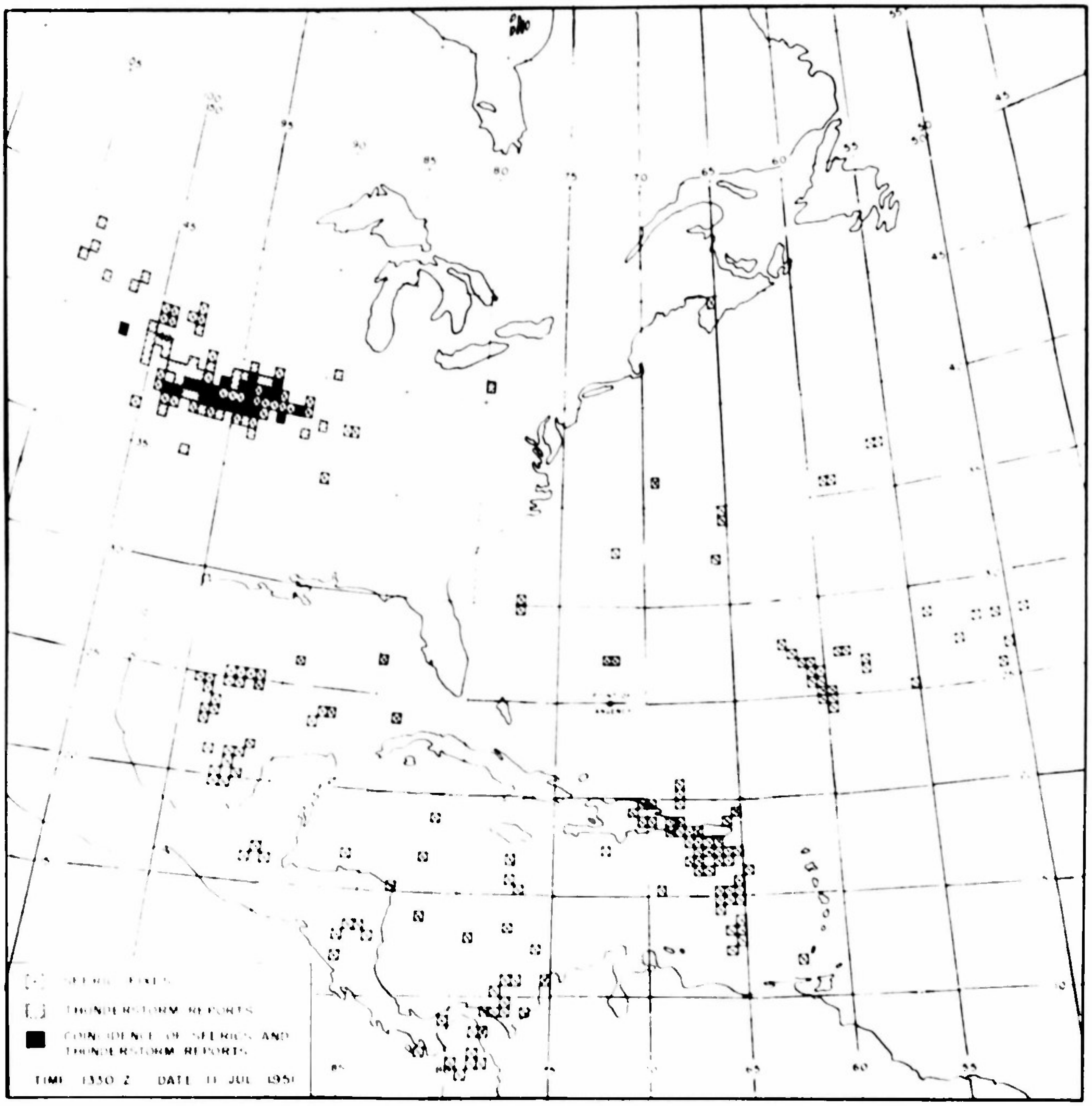

THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 1330 Z DATE 11 JUL 1951

Fig. 55

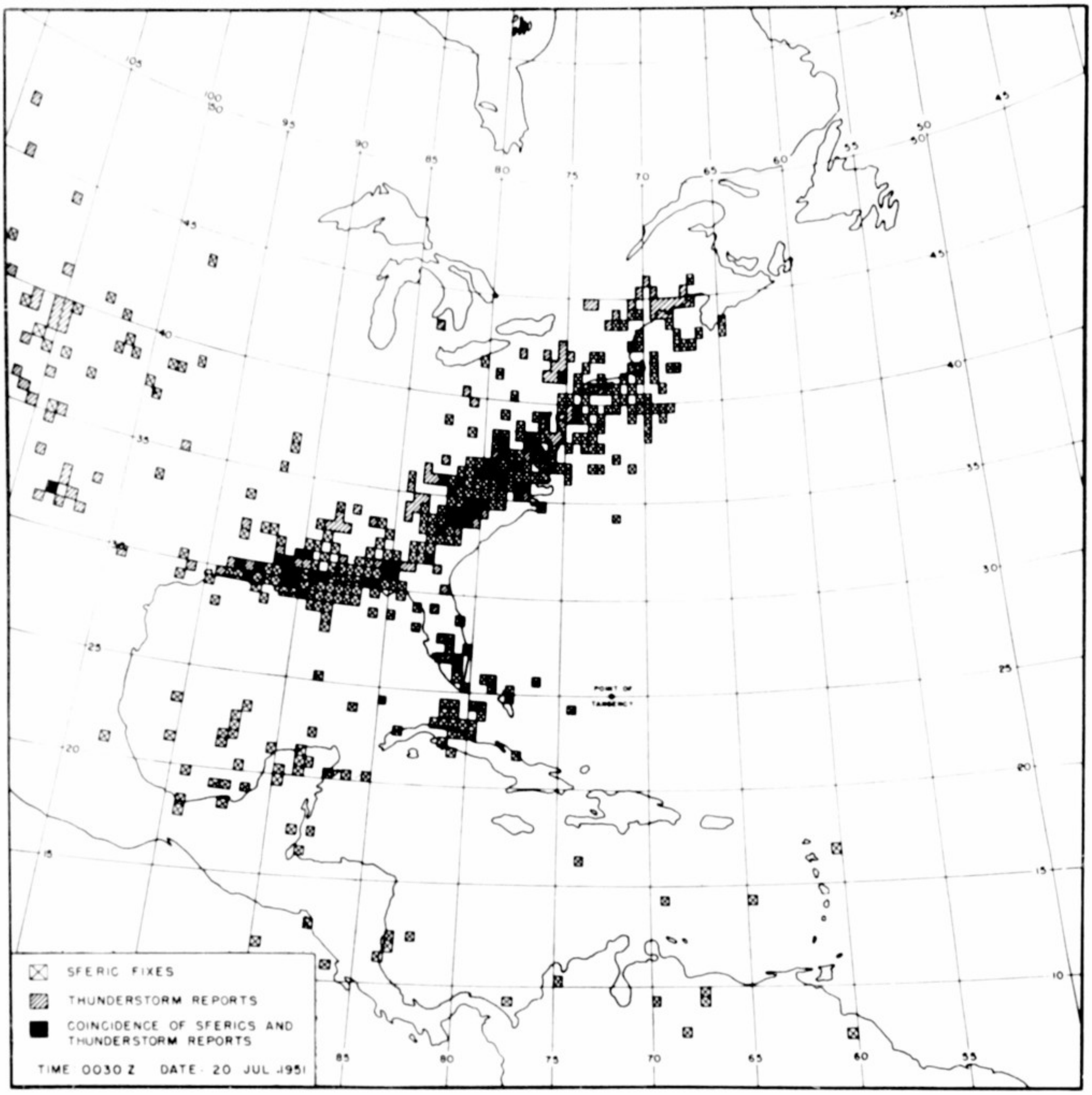

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 0030 Z DATE 20 JUL 1951
POINT OF TANGENCY

Fig. 56

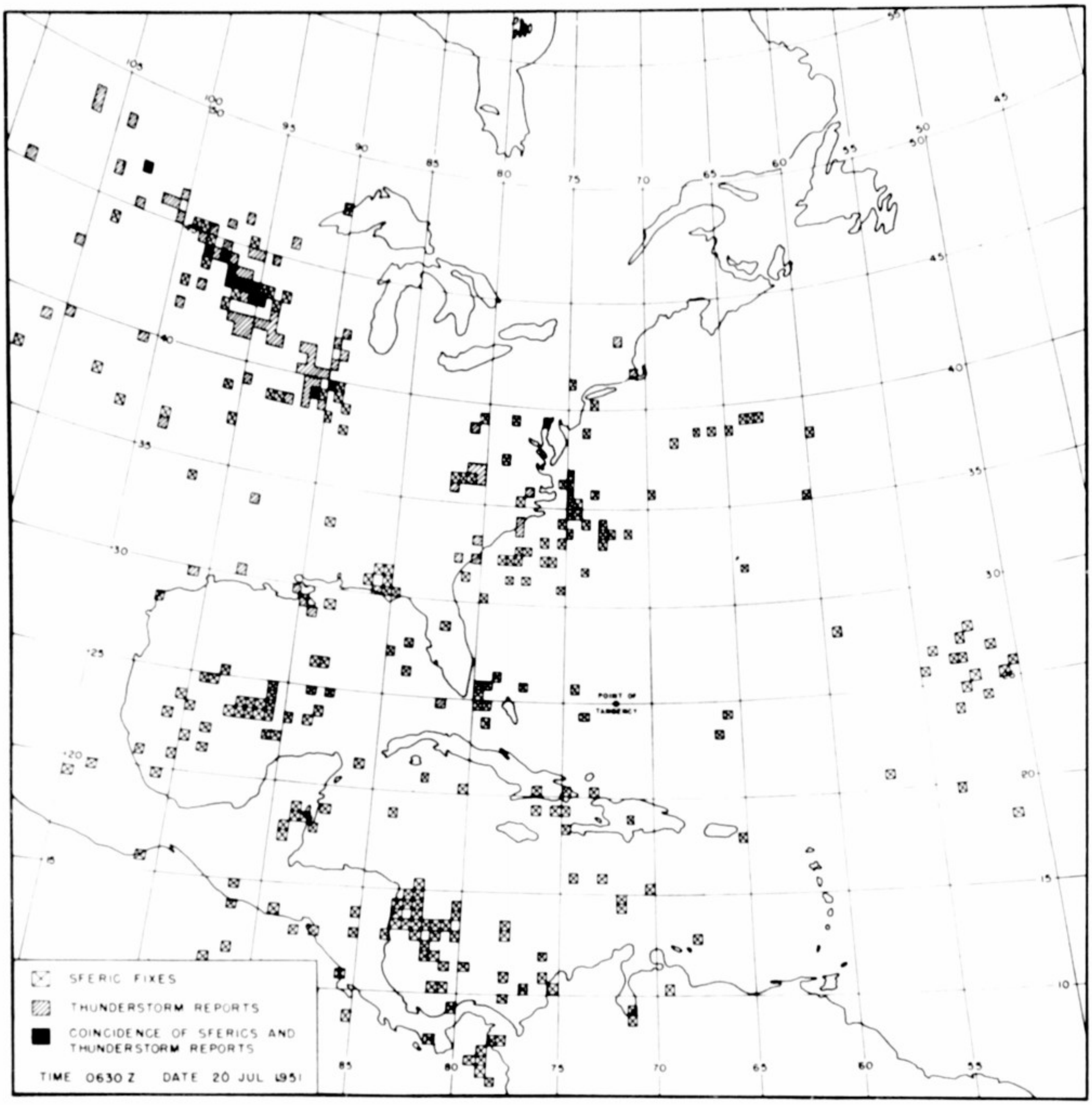

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 0630 Z DATE 20 JUL 1951

Fig. 57

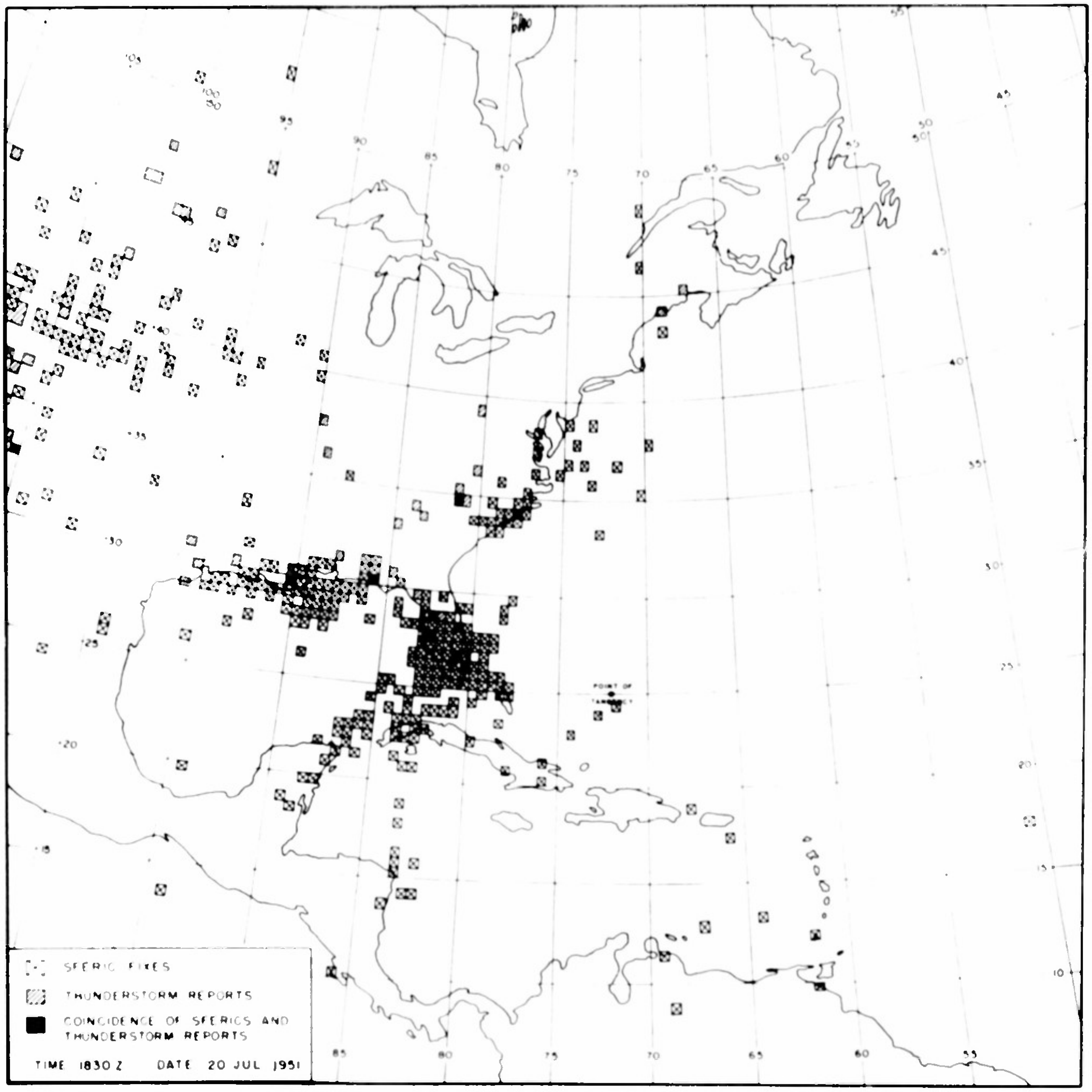

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
TIME 1830 Z DATE 20 JUL 1951
POINT OF TANGENCY

Fig. 58

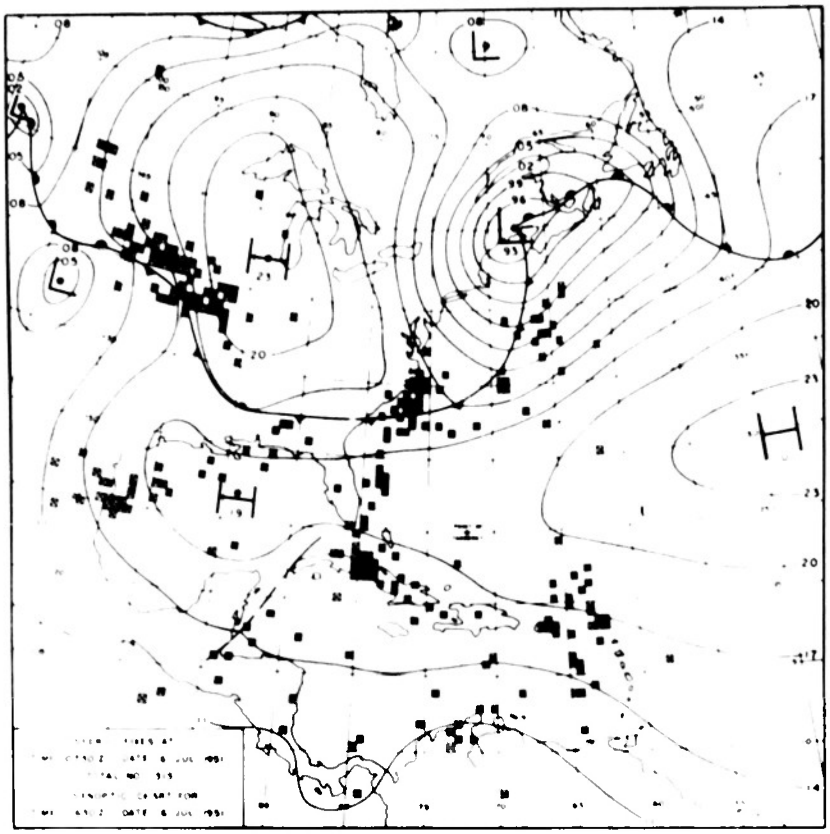


Fig. 59

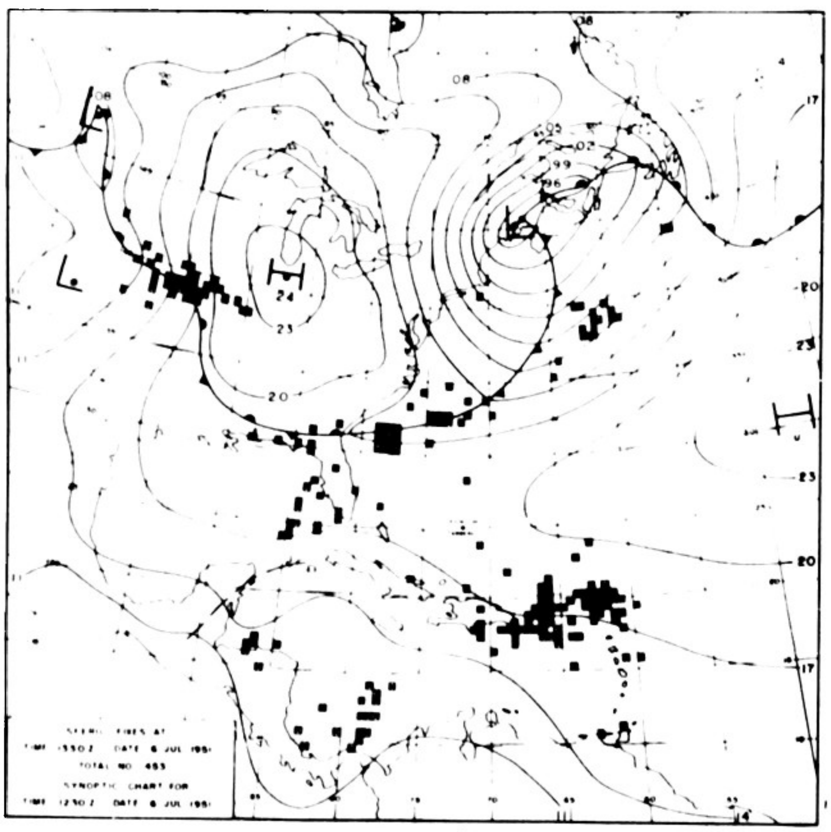


Fig. 60

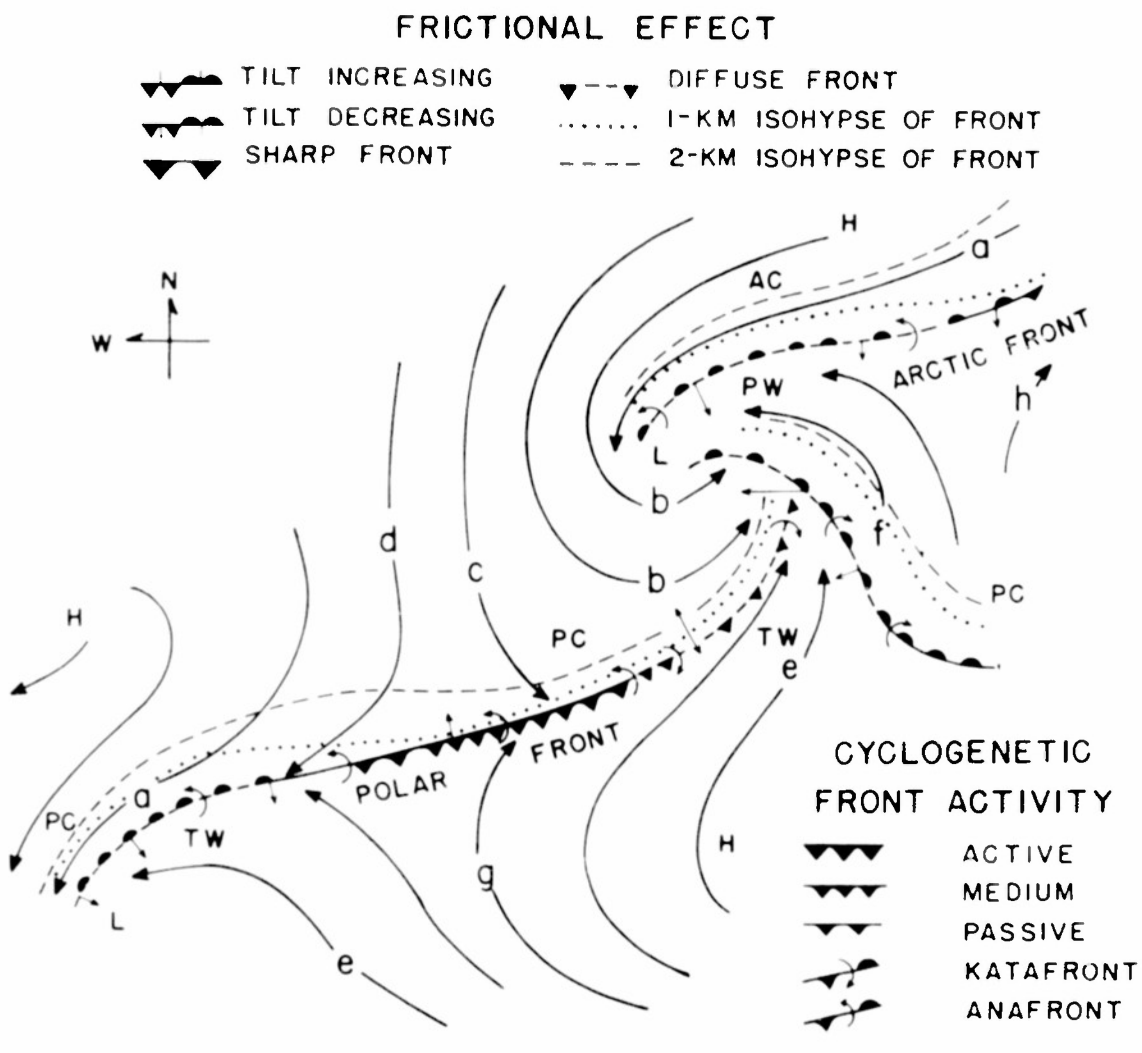


Fig. 61 Frontal Activity and Passivity According to Bergeron; and Vorticity Dynamics of Cyclones According to Bjerknes

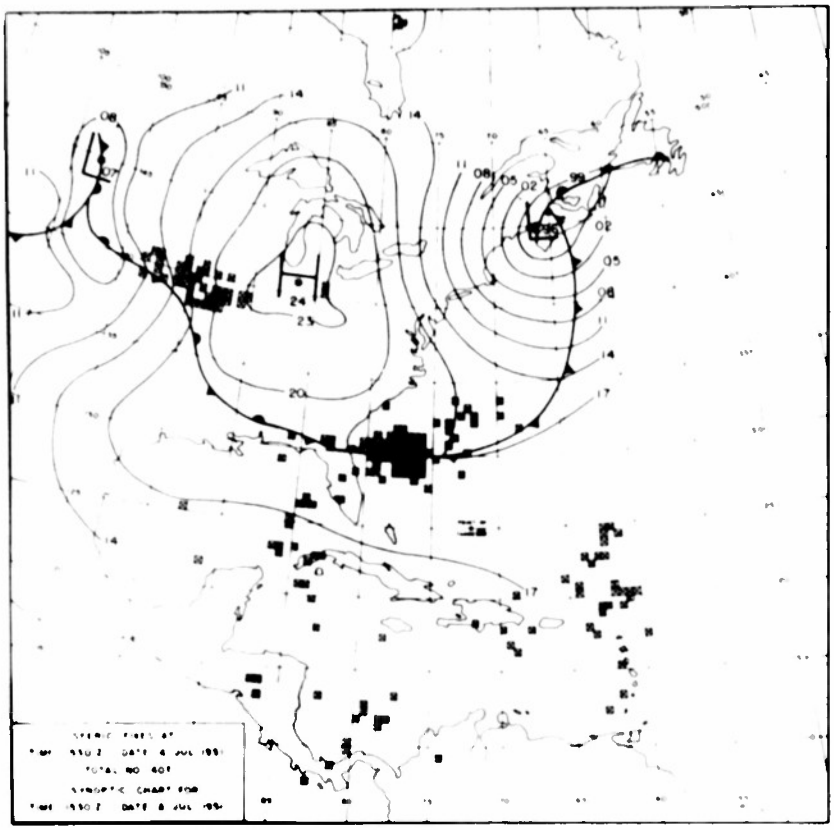


Fig. 62

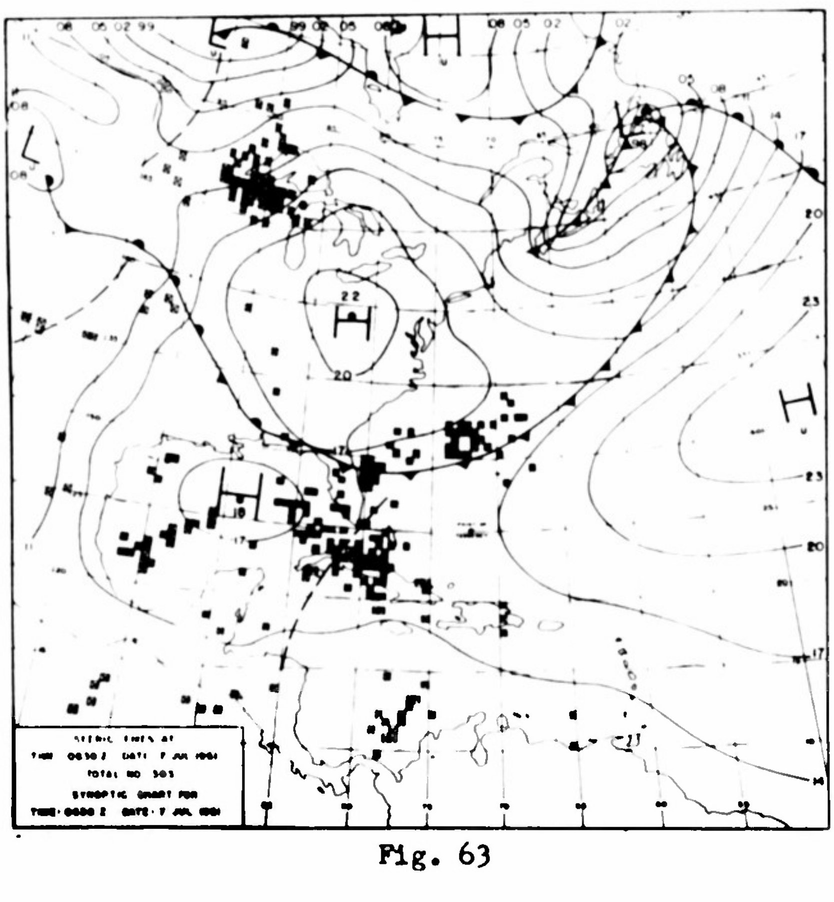


Fig. 63

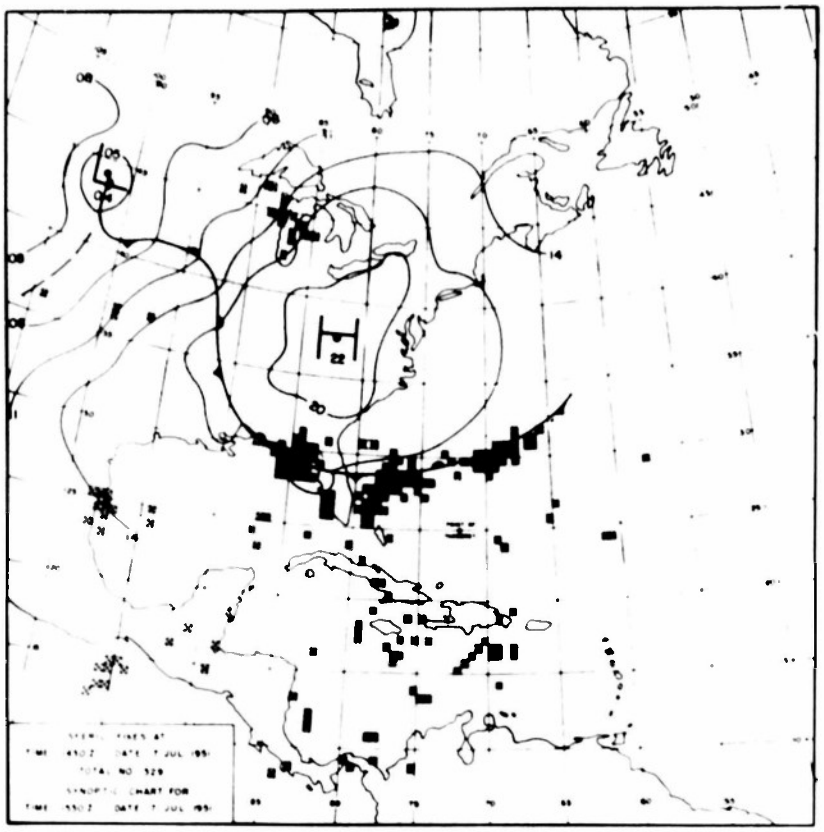


Fig. 64

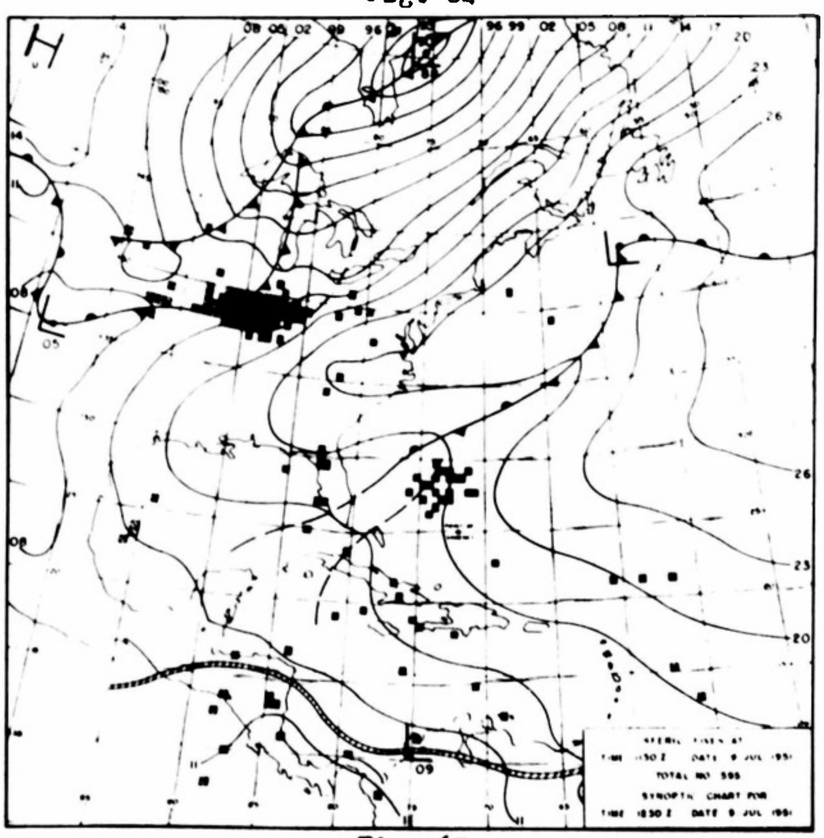


Fig. 65

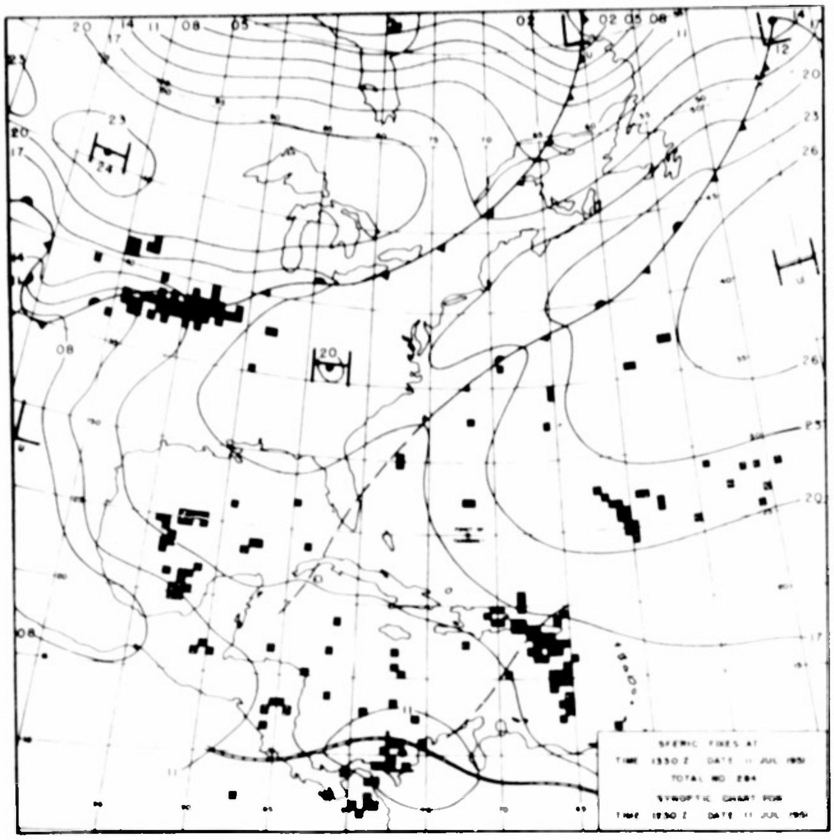

SFERIC FIXES AT
TIME 1330 Z DATE 11 JUL 1951
TOTAL NO 284
SYNOPTIC CHART FOR
TIME 1230 Z DATE 11 JUL 1951

Fig. 66

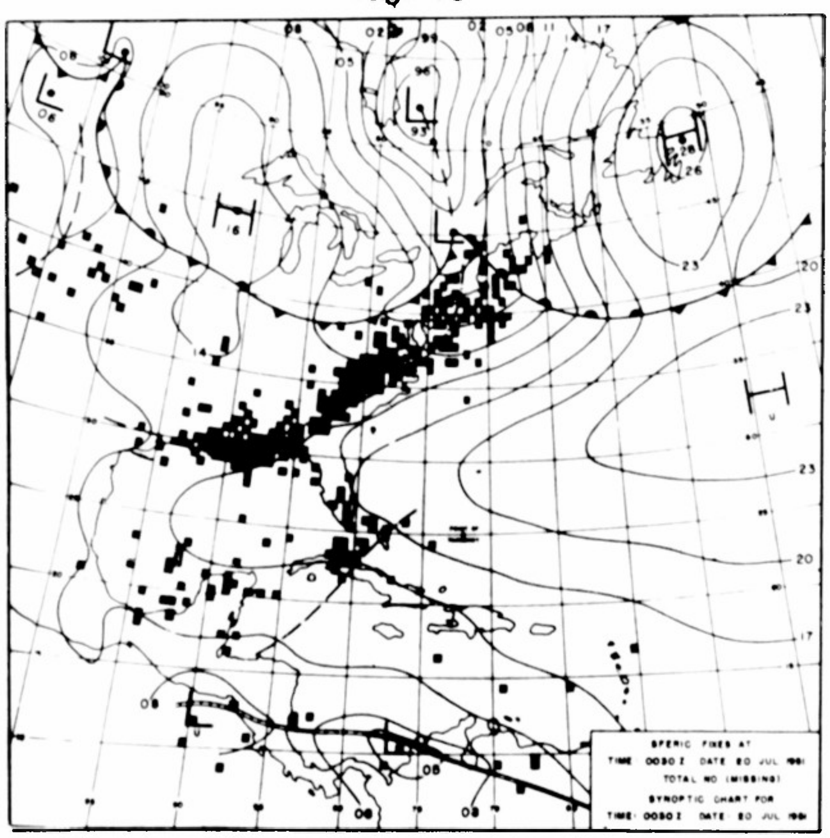

SFERIC FIXES AT
TIME 0030 Z DATE 20 JUL 1951
TOTAL NO (MISSING)
SYNOPTIC CHART FOR
TIME 0030 Z DATE 20 JUL 1951

Fig. 67

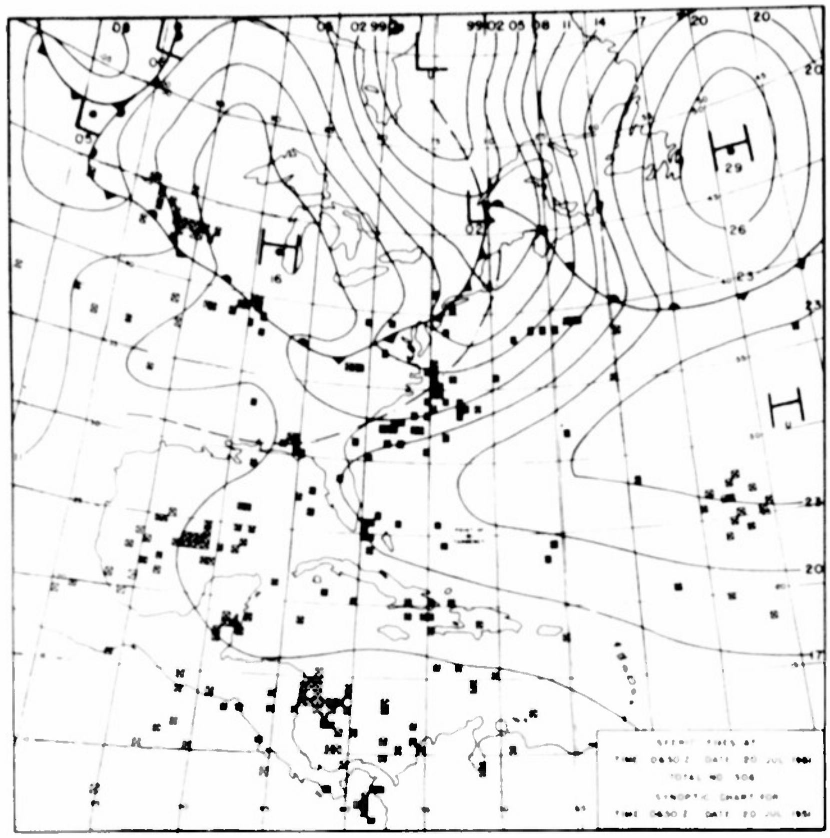


Fig. 68

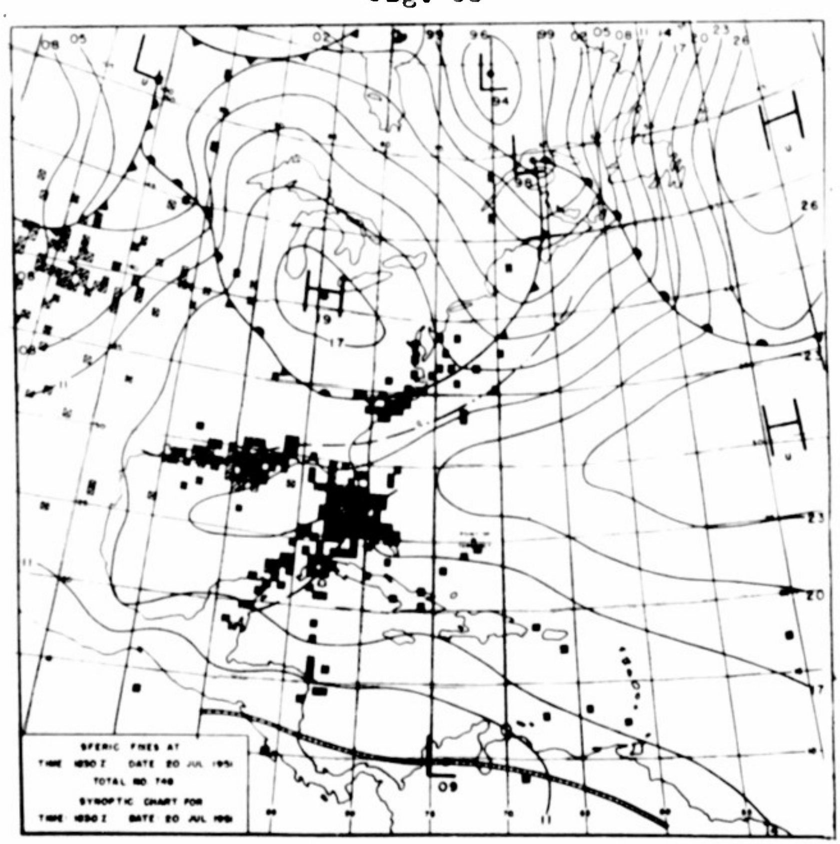


Fig. 69

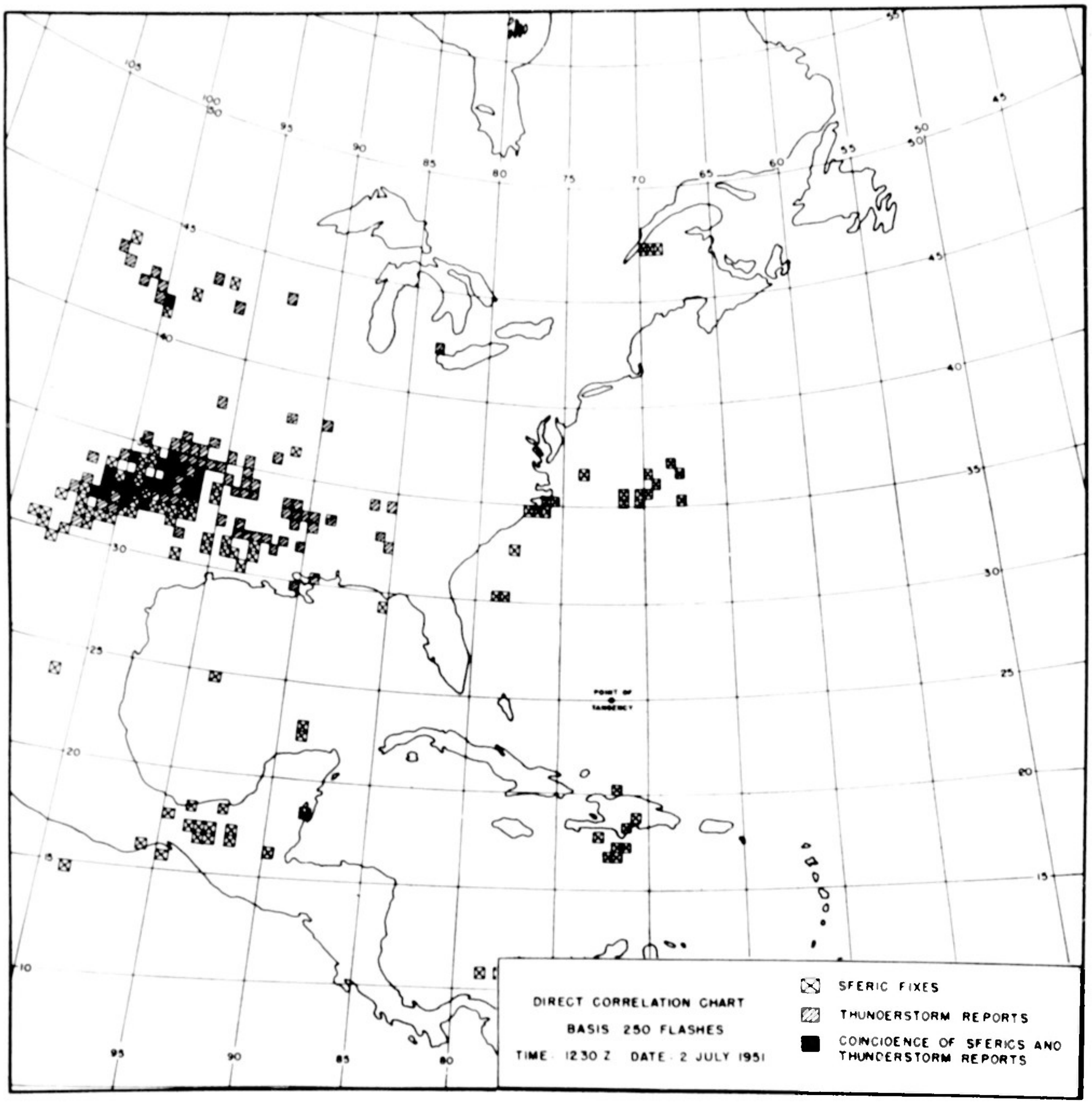

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1230 Z DATE 2 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 70

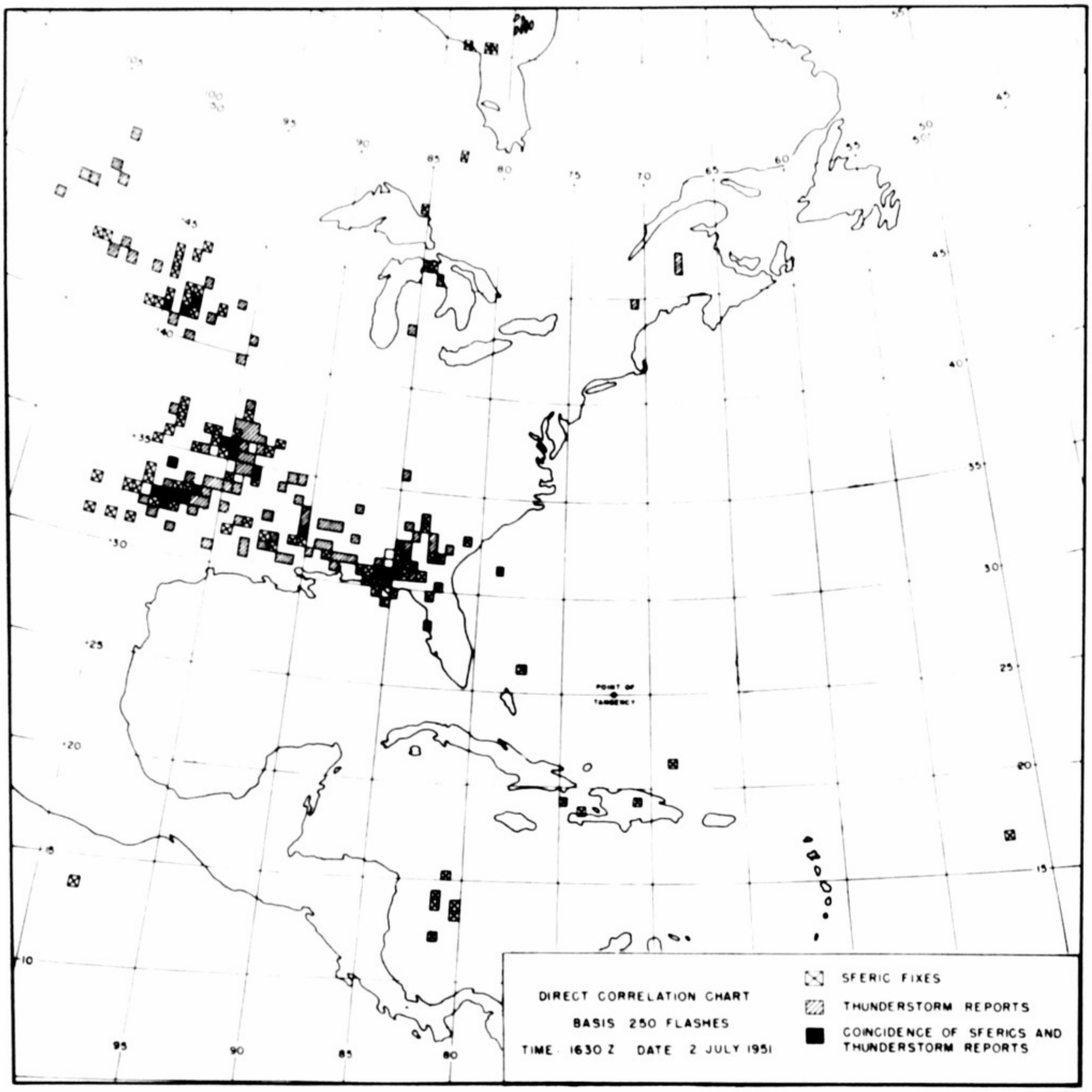

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1630 Z DATE 2 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 71

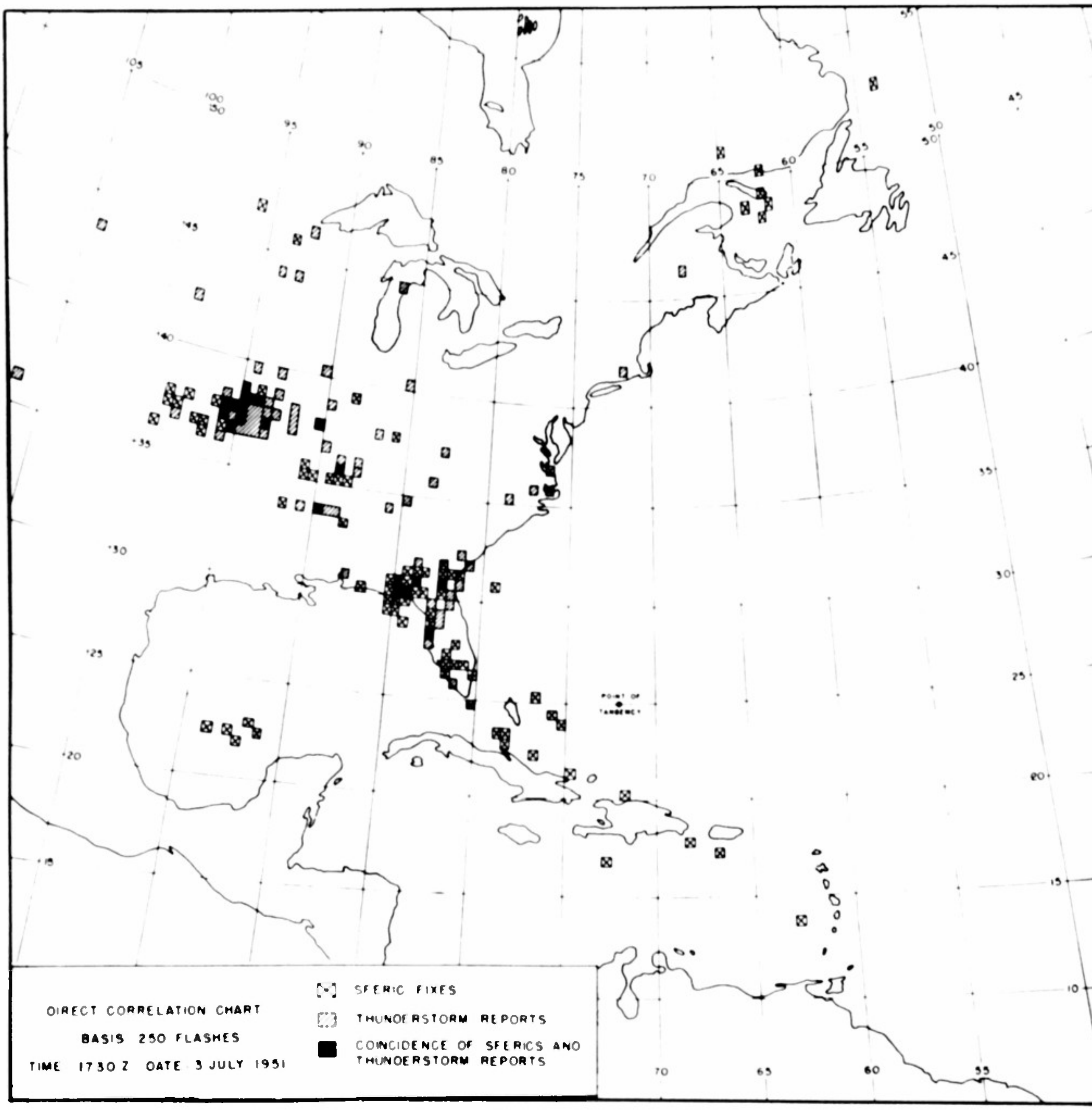

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1730 Z DATE 3 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS

Fig. 72

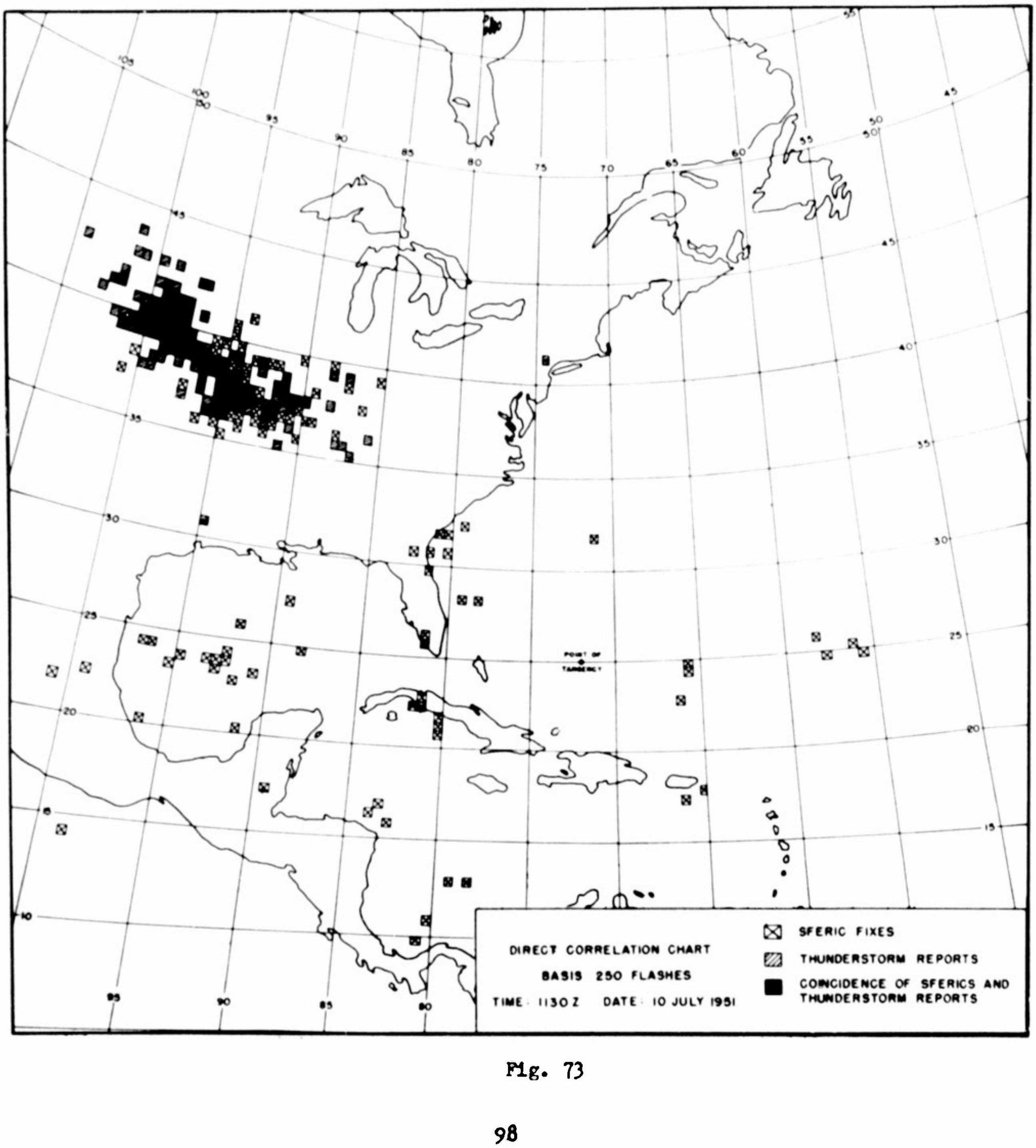

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME: 1130 Z DATE: 10 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 73

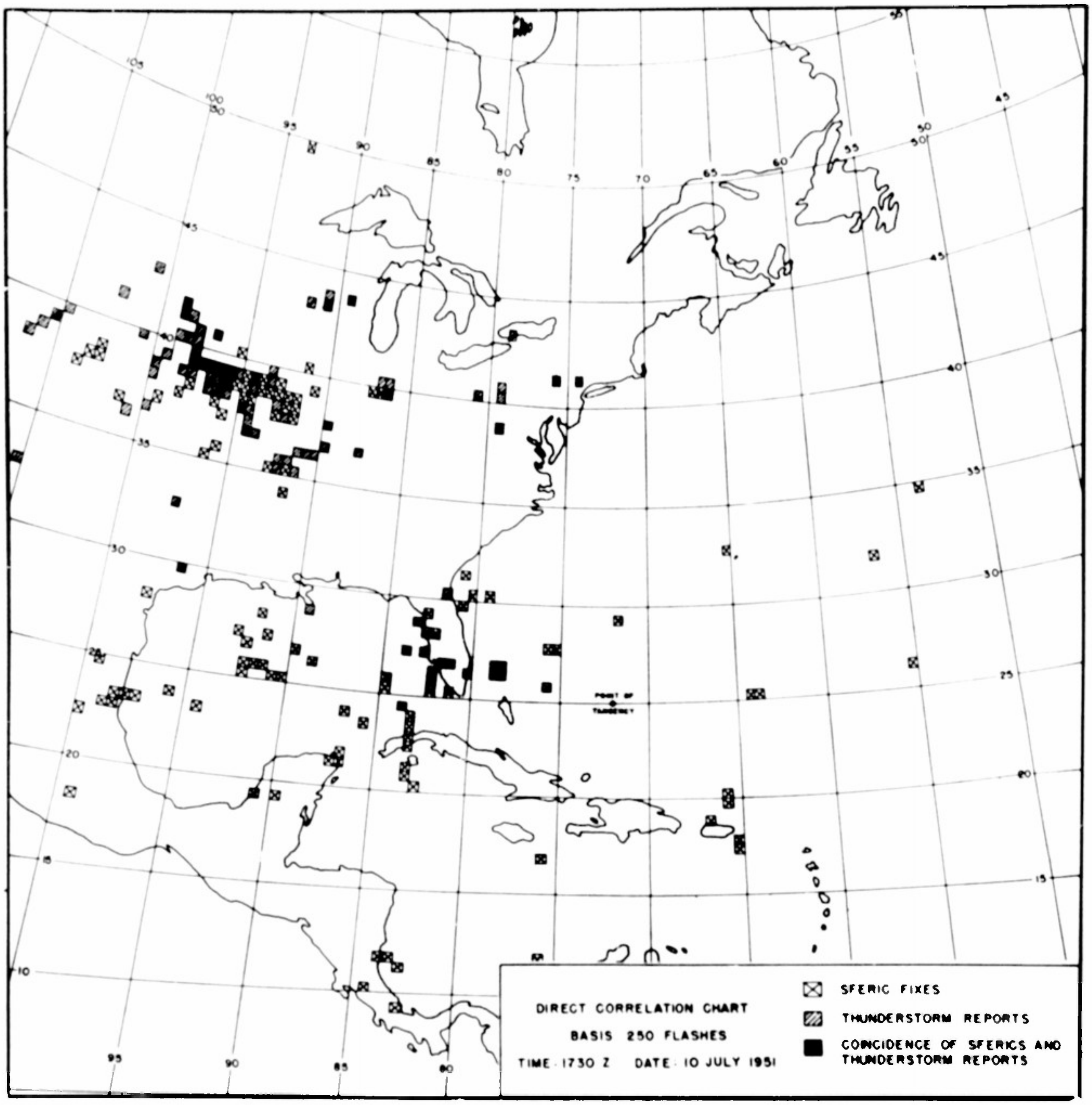

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1730 Z DATE 10 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS

Fig. 74

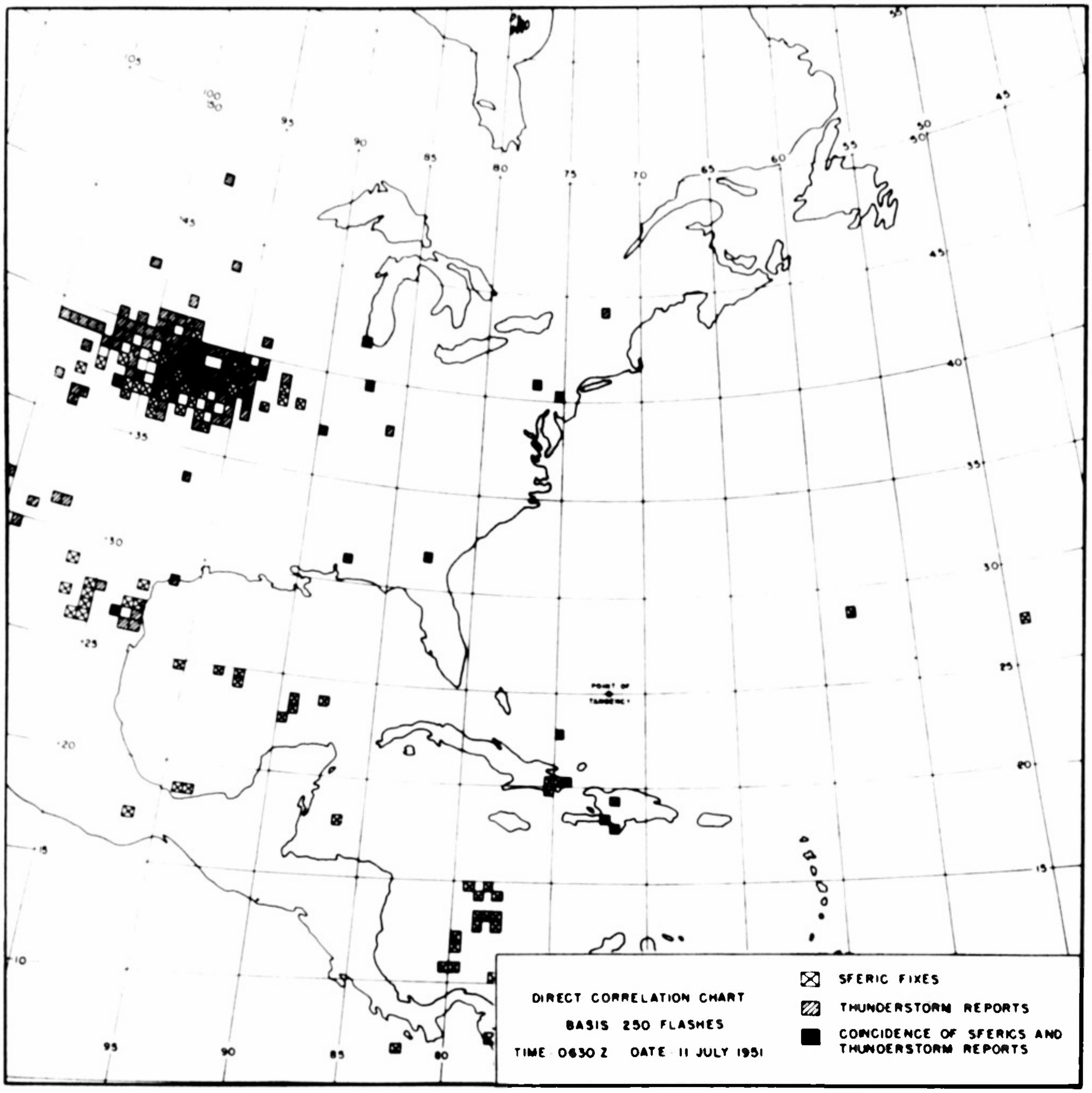

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 0630 Z DATE 11 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS

Fig. 75

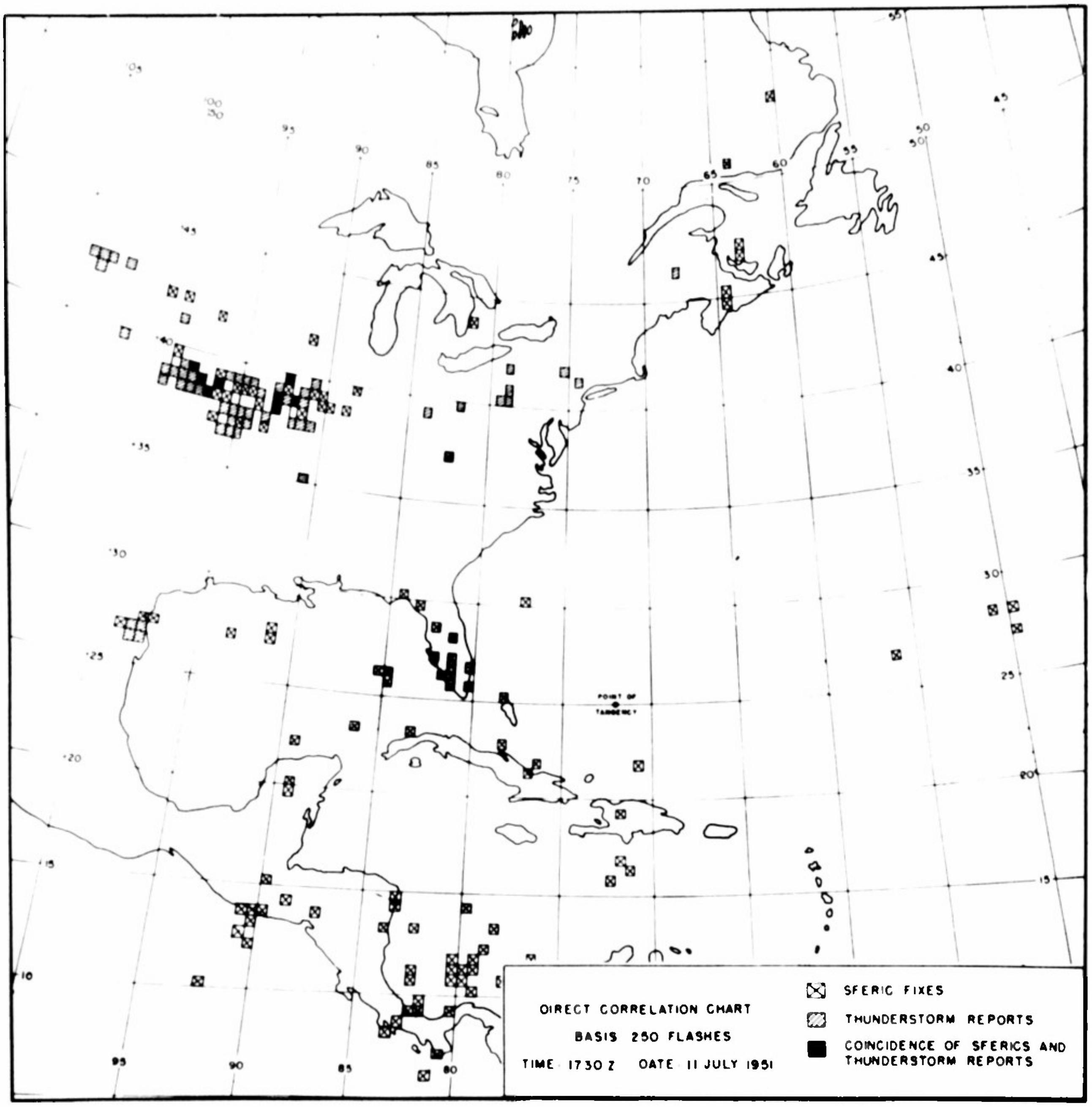

OIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1730 Z OATE 11 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 76

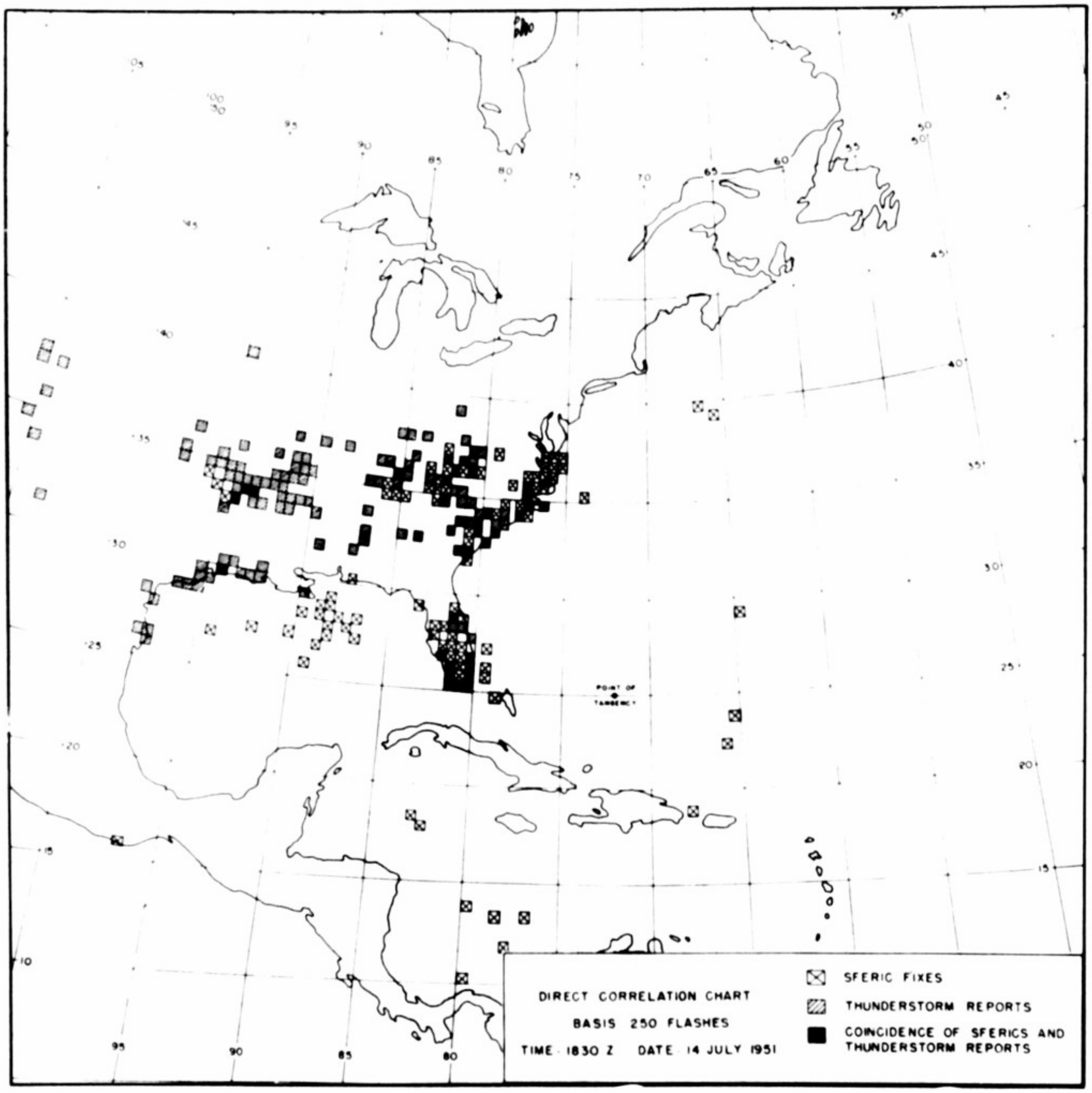

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1830 Z DATE 14 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 77

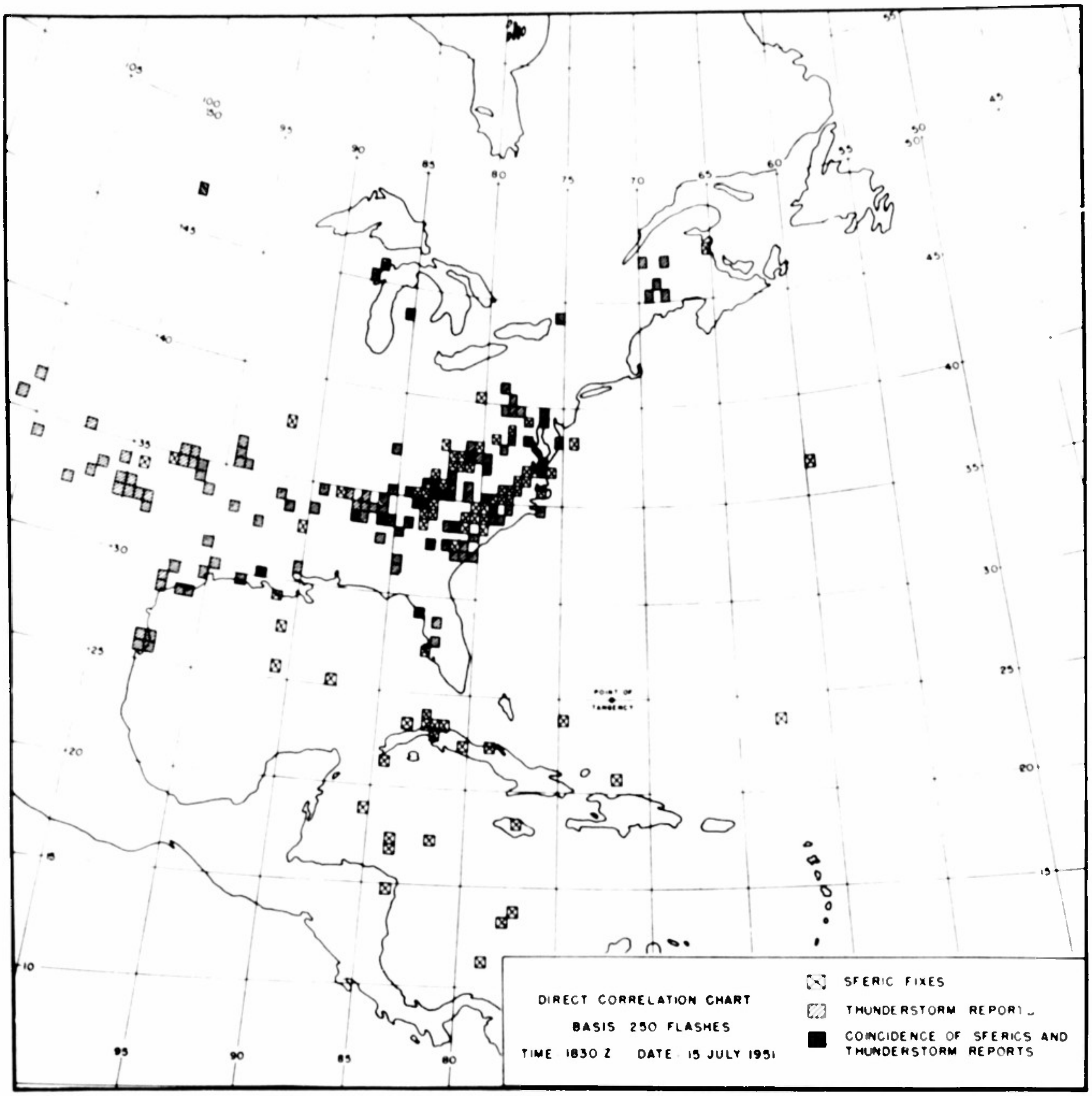

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1830 Z DATE 15 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 78

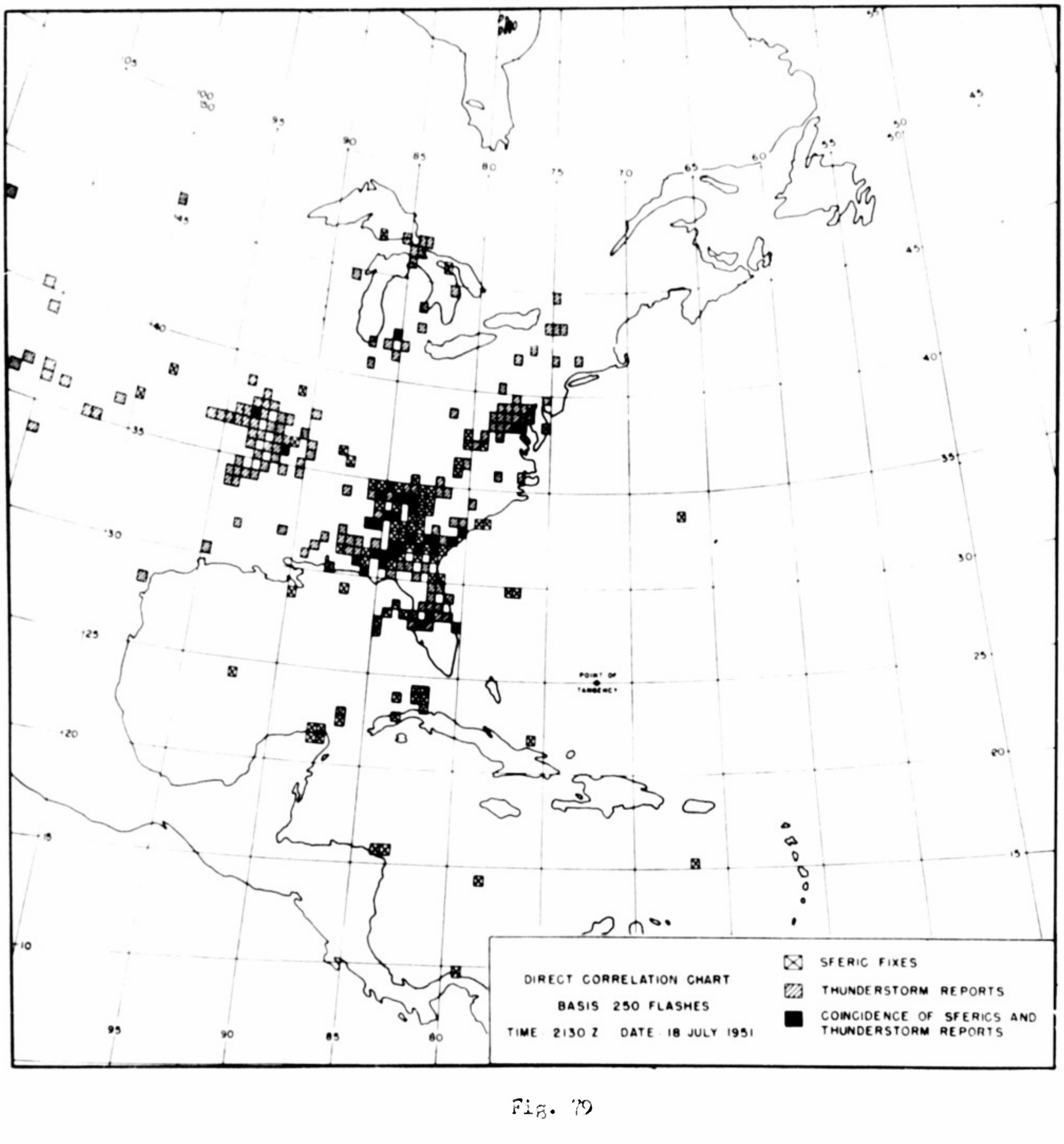

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 2130 Z DATE 18 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 79

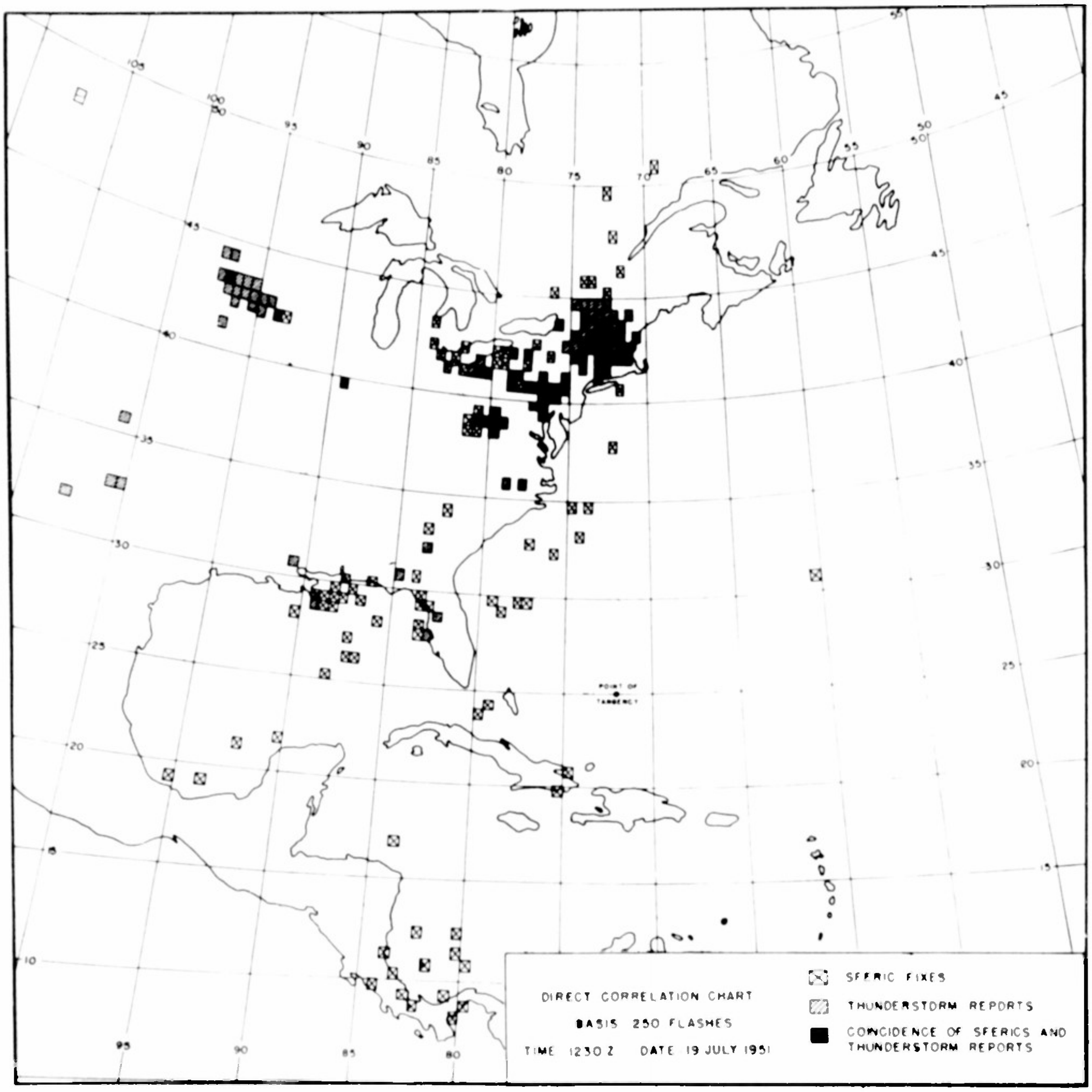

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1230 Z DATE 19 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 80

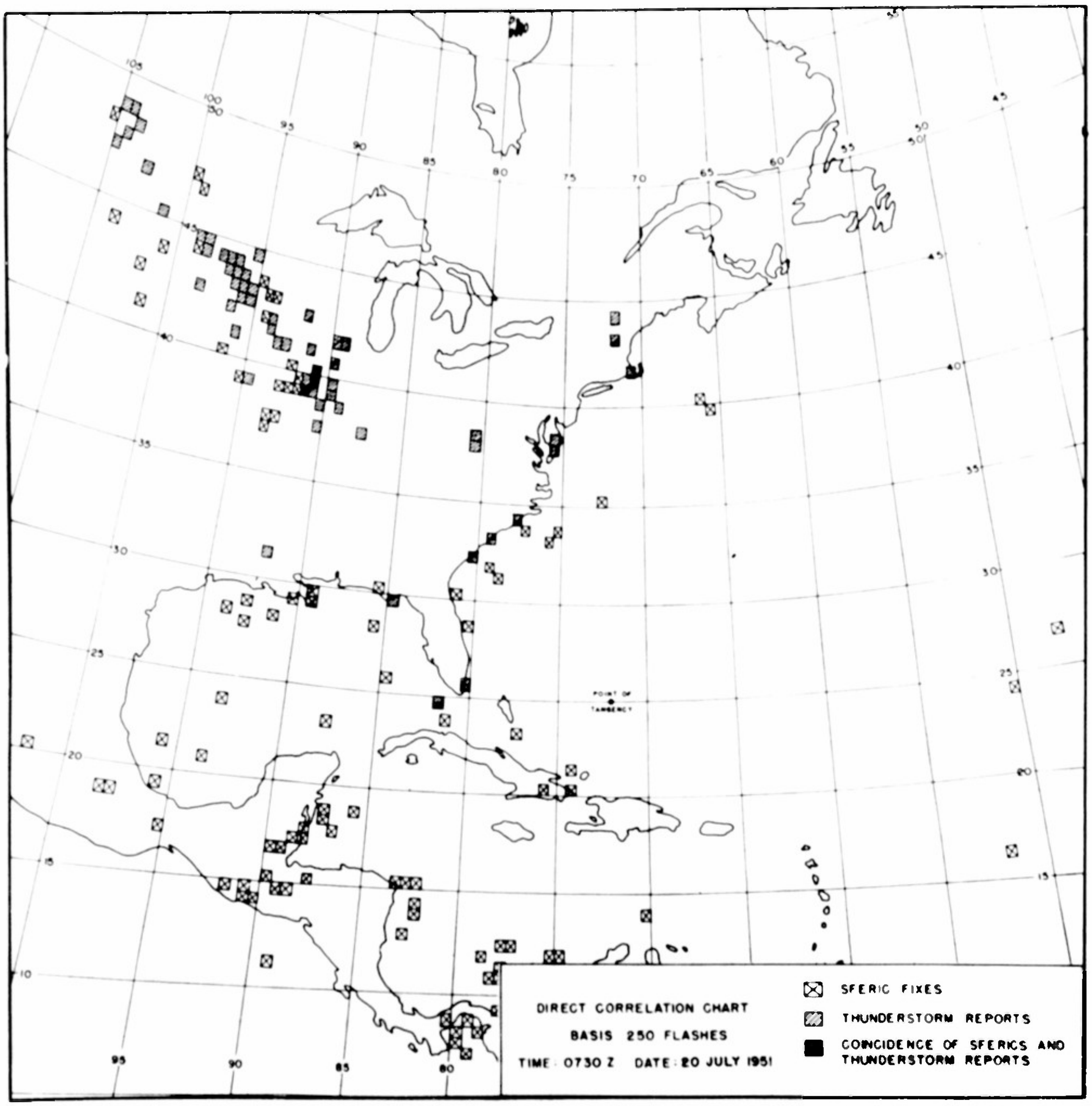

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 0730 Z DATE 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 81

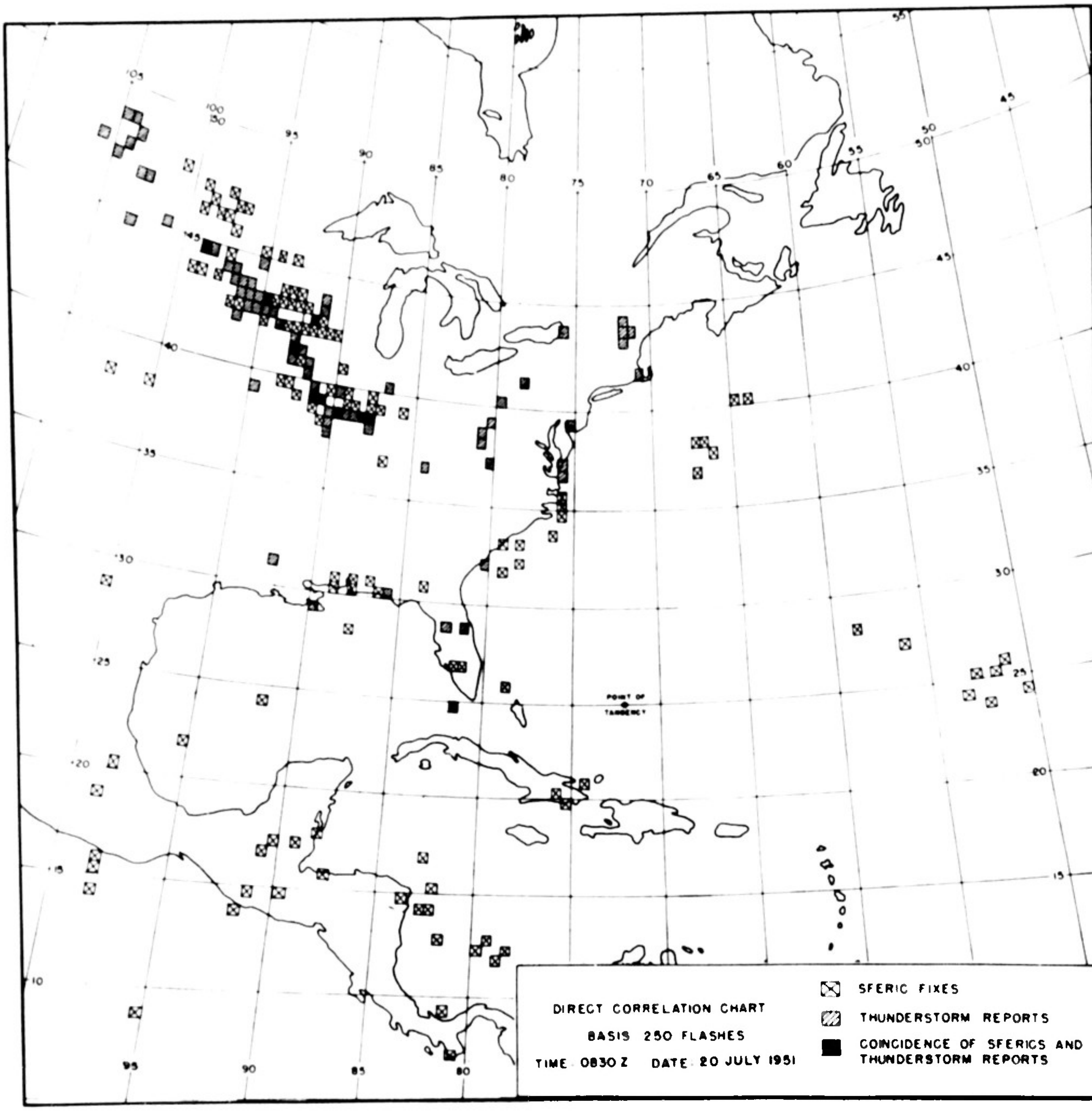

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 0830 Z DATE 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 82

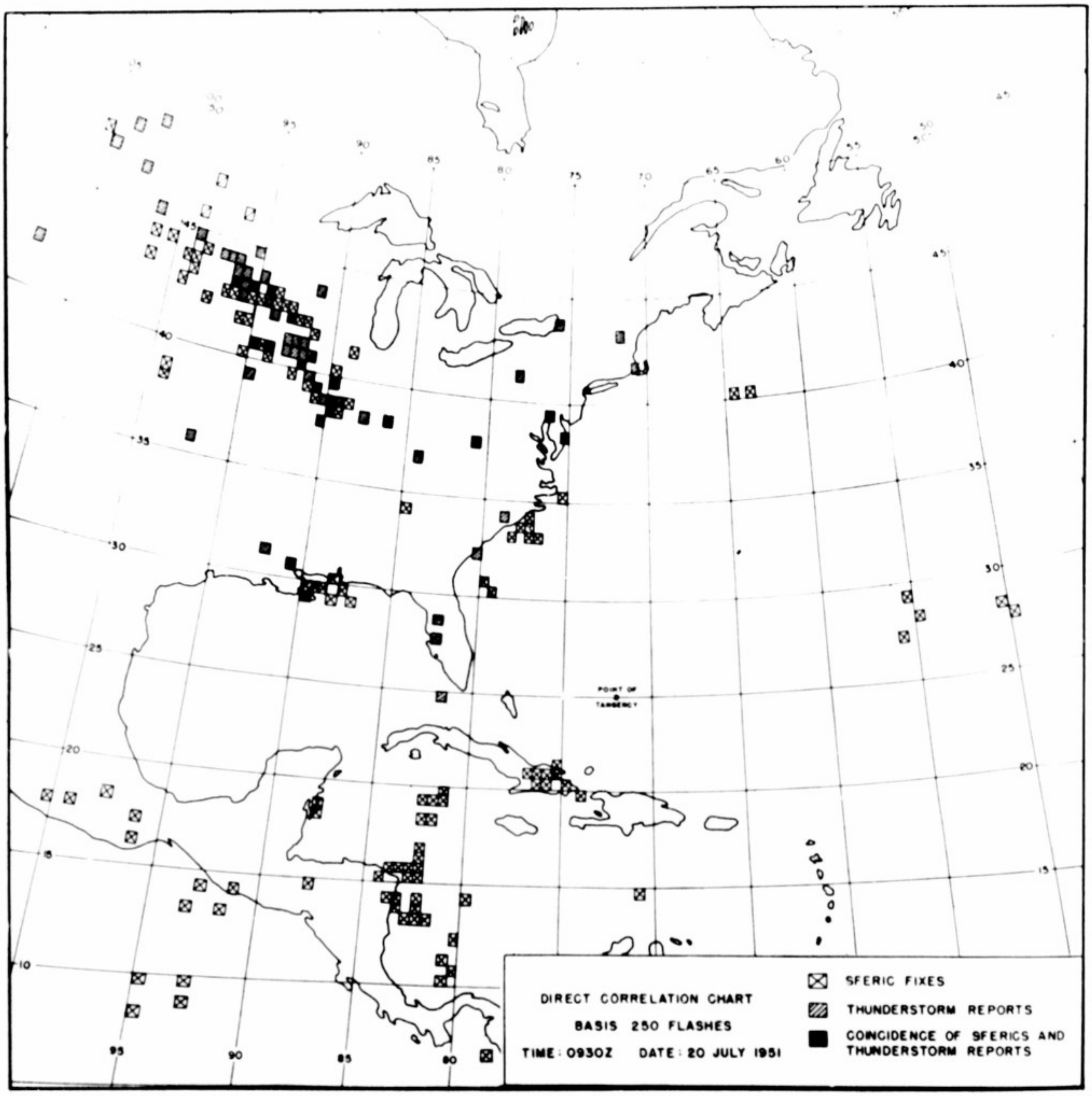

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME: 0930Z DATE: 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 83

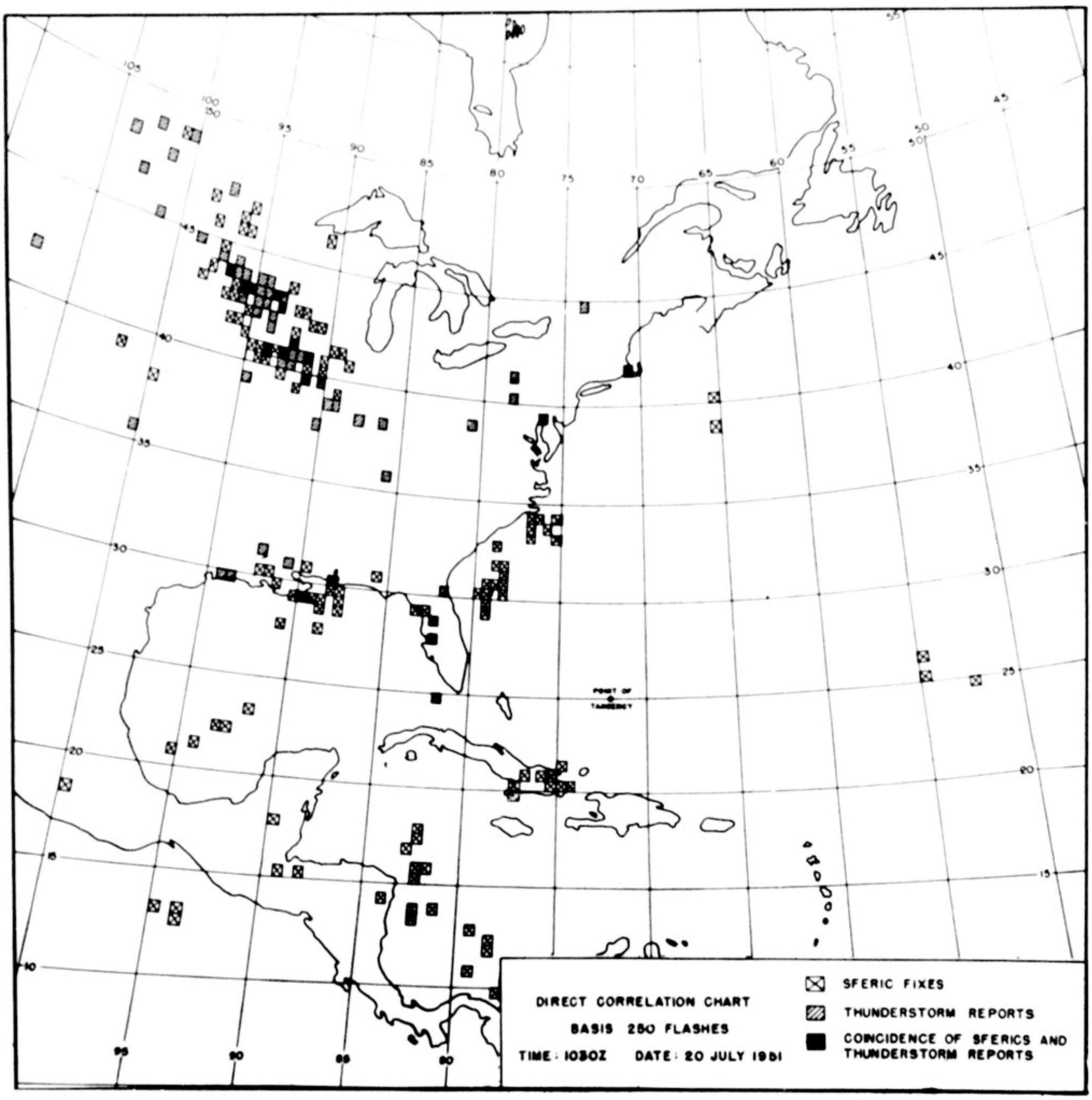

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME: 1030Z DATE: 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 84

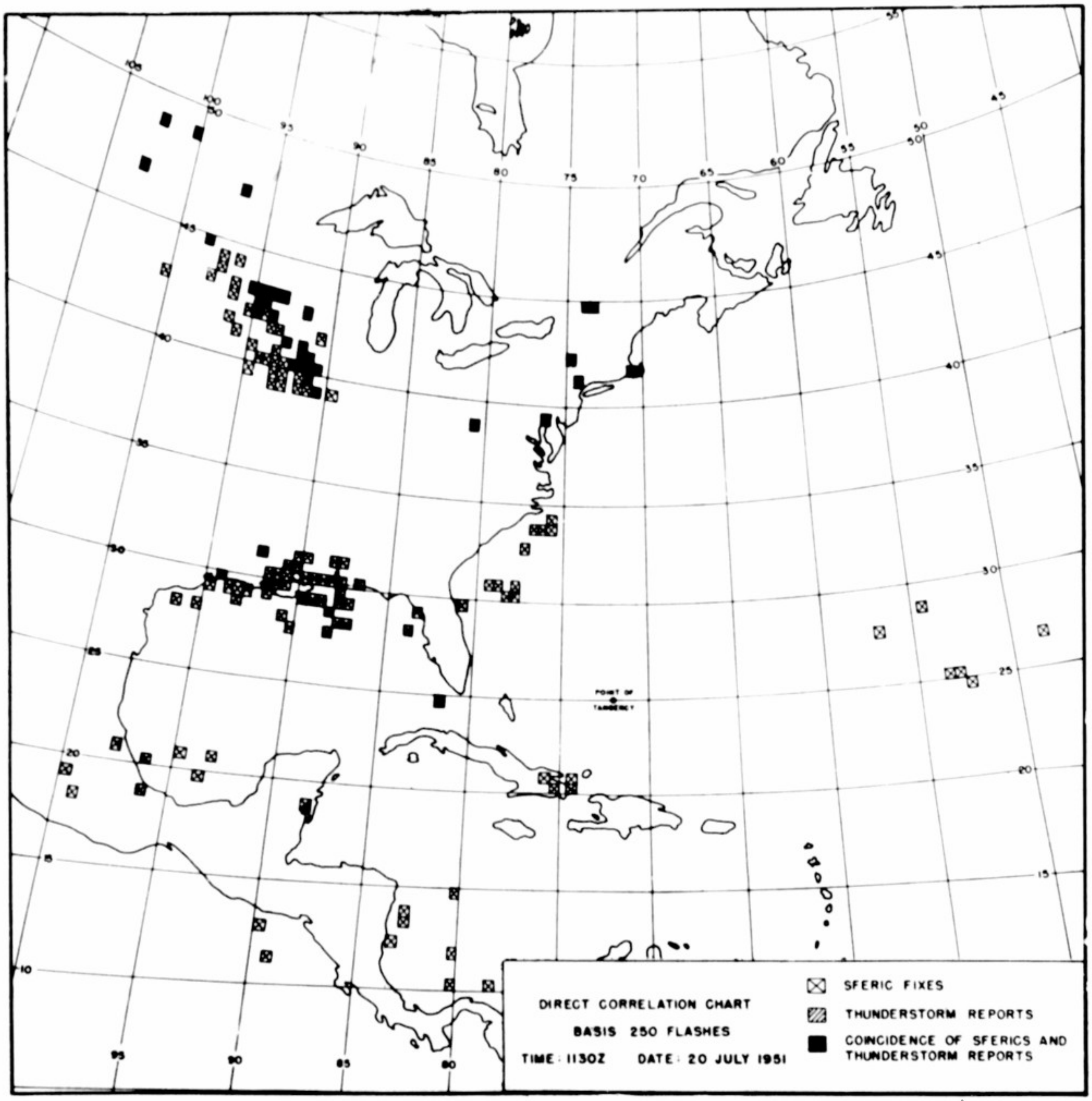

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME: 1130Z DATE: 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 85

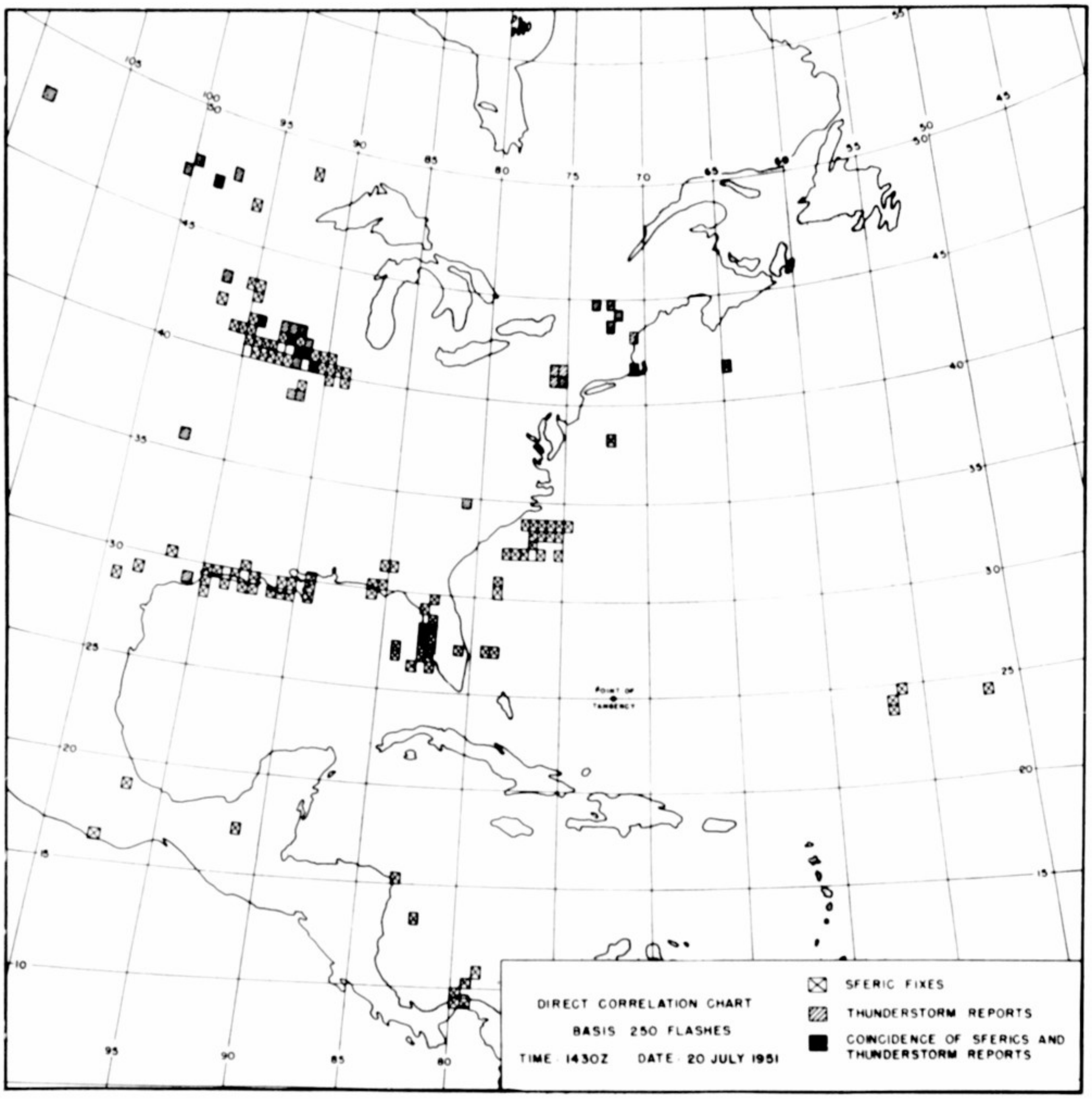

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1430Z DATE 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 86

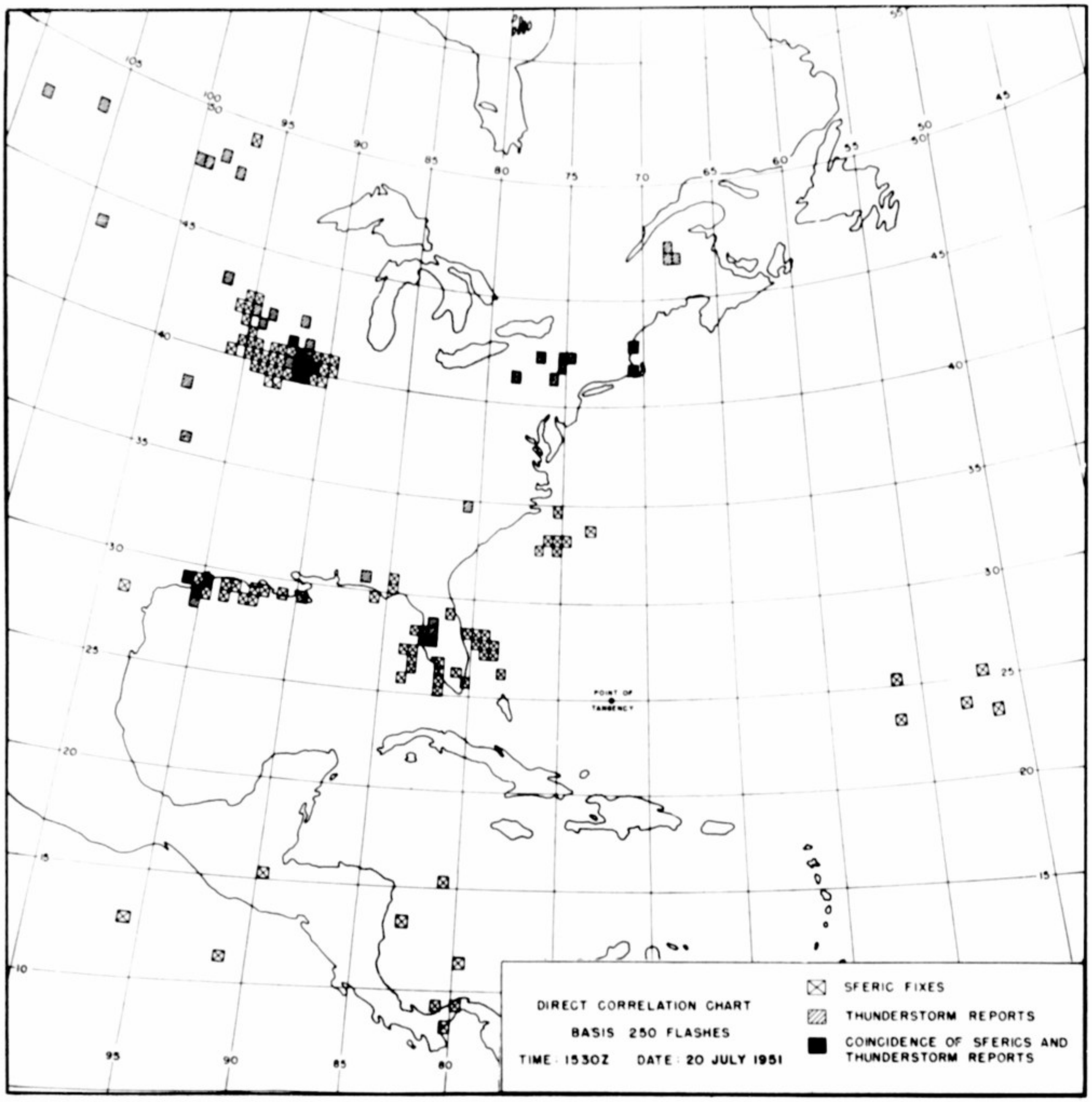

SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1530Z DATE 20 JULY 1951

Fig. 87

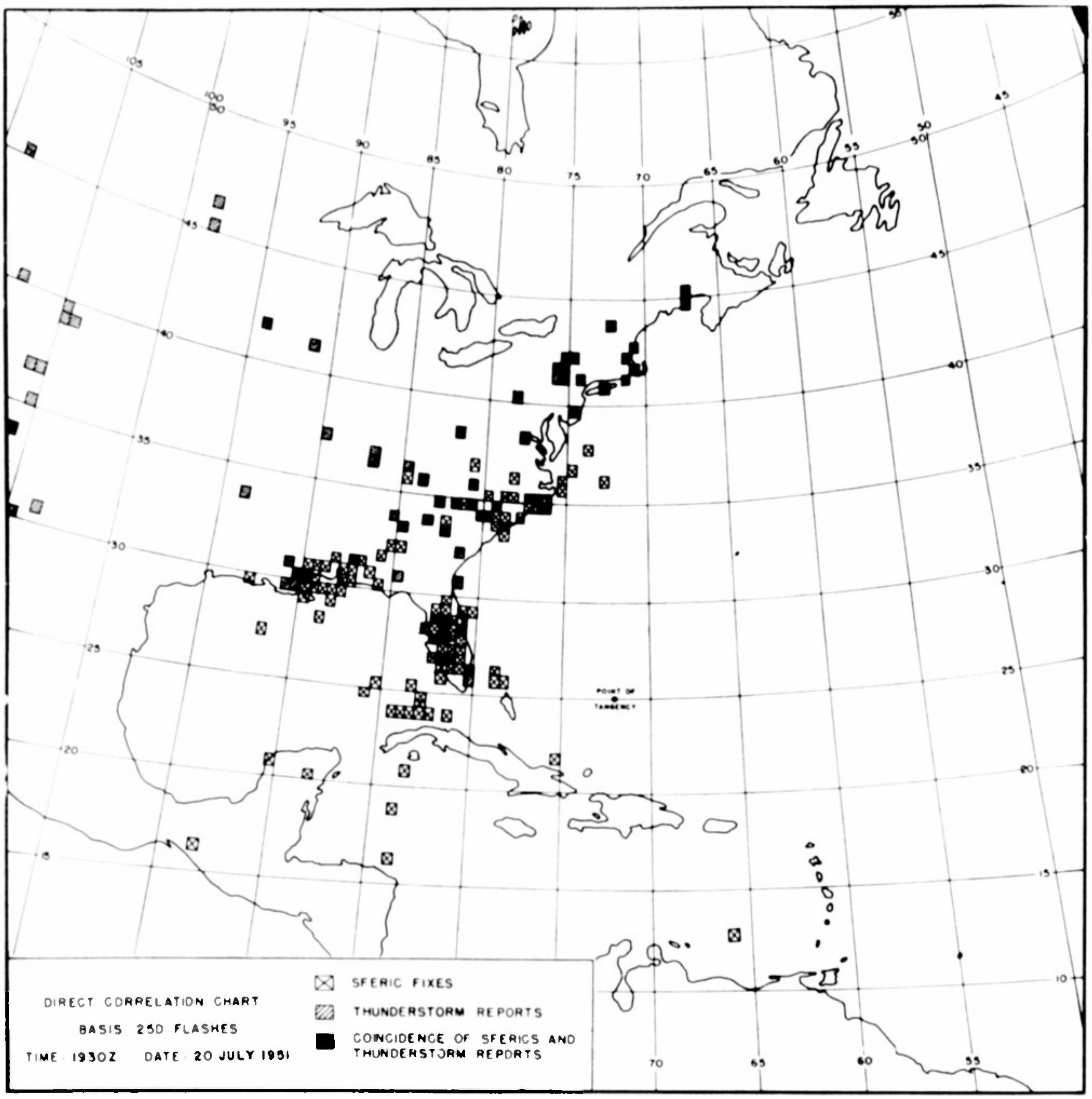

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 1930Z DATE 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 88

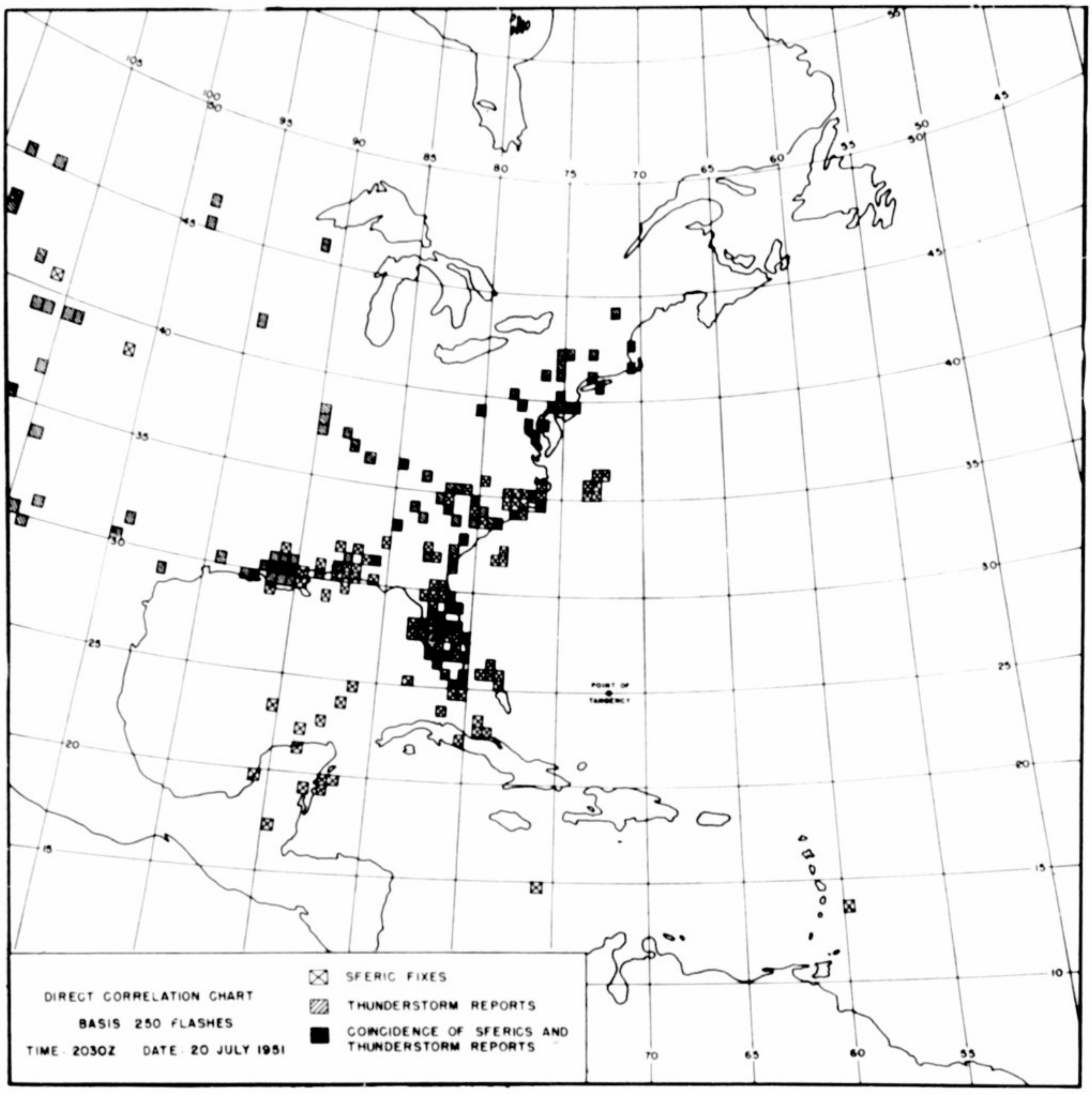

DIRECT CORRELATION CHART
BASIS 250 FLASHES
TIME 2030Z DATE 20 JULY 1951
SFERIC FIXES
THUNDERSTORM REPORTS
COINCIDENCE OF SFERICS AND THUNDERSTORM REPORTS
POINT OF TANGENCY

Fig. 89

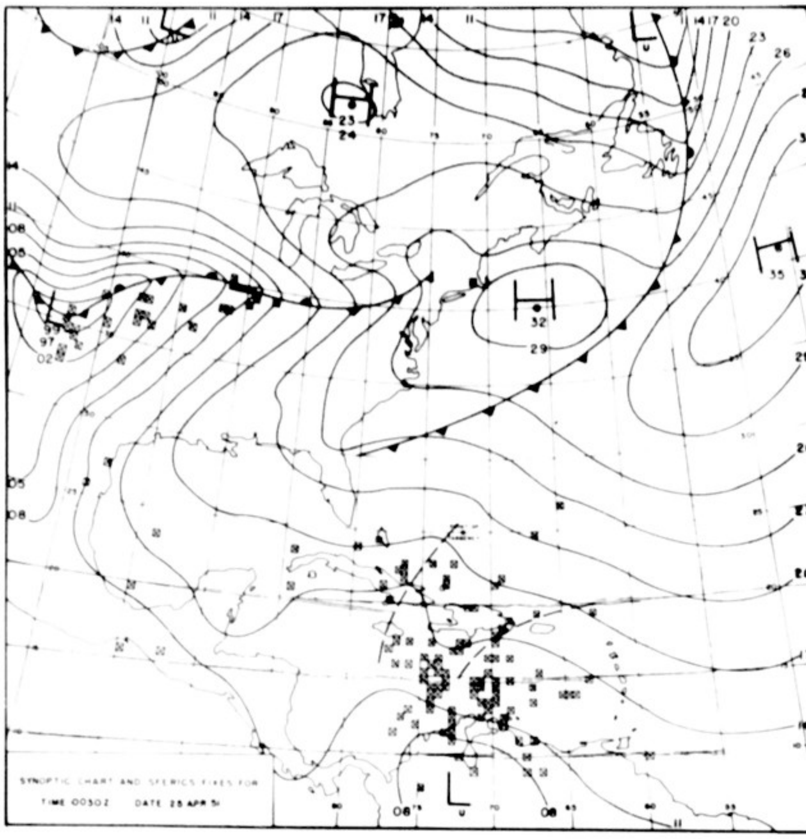


Fig. 90

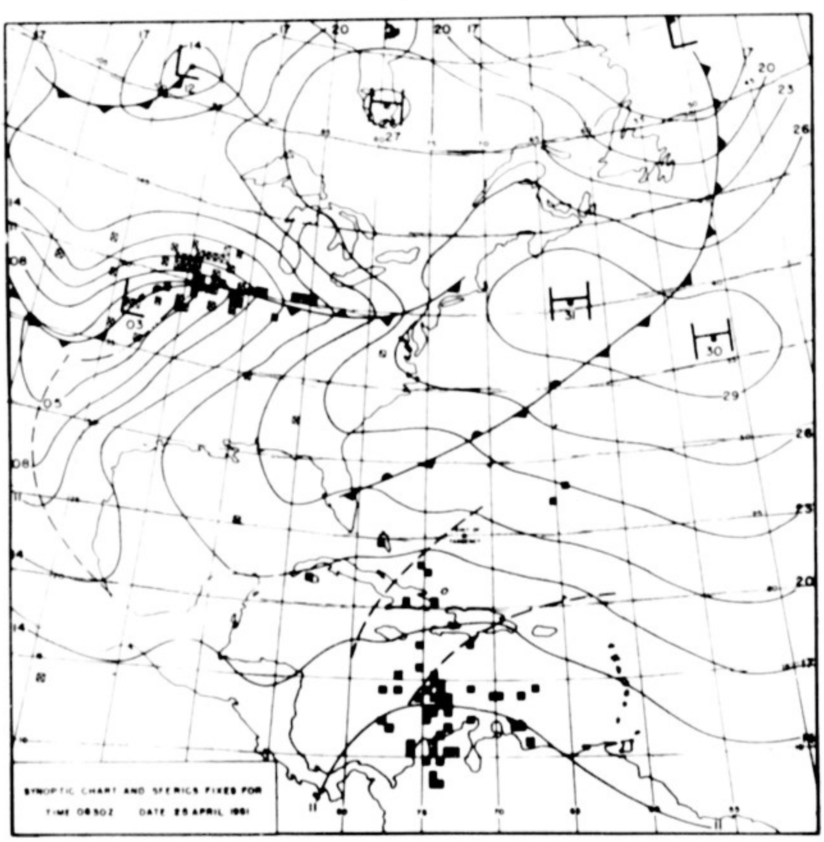


Fig. 91

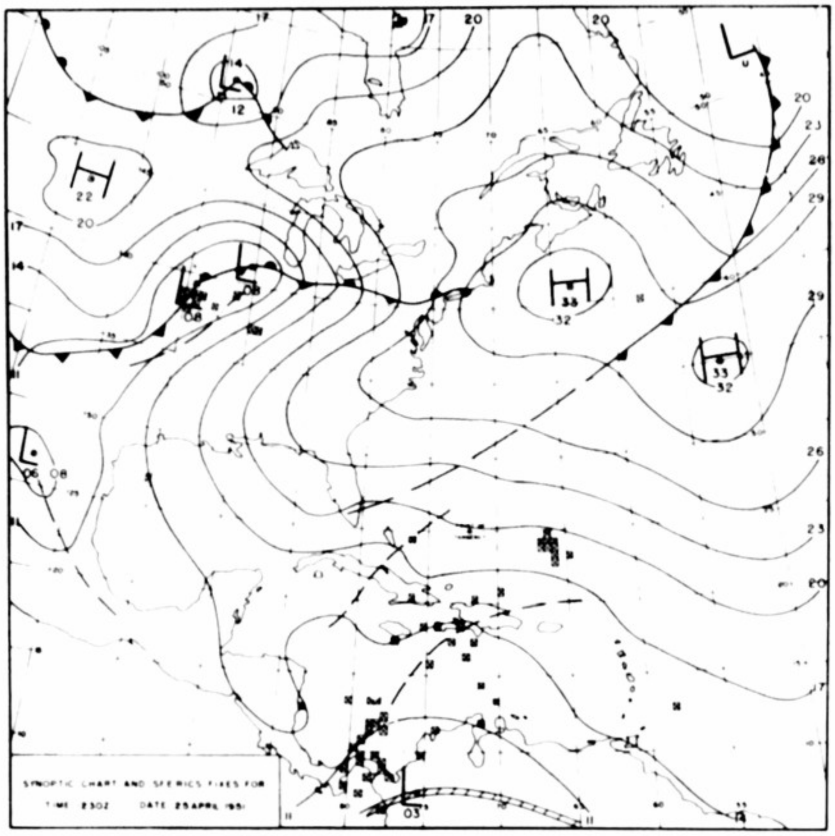

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 2302 DATE 25 APRIL 1961

Fig. 92

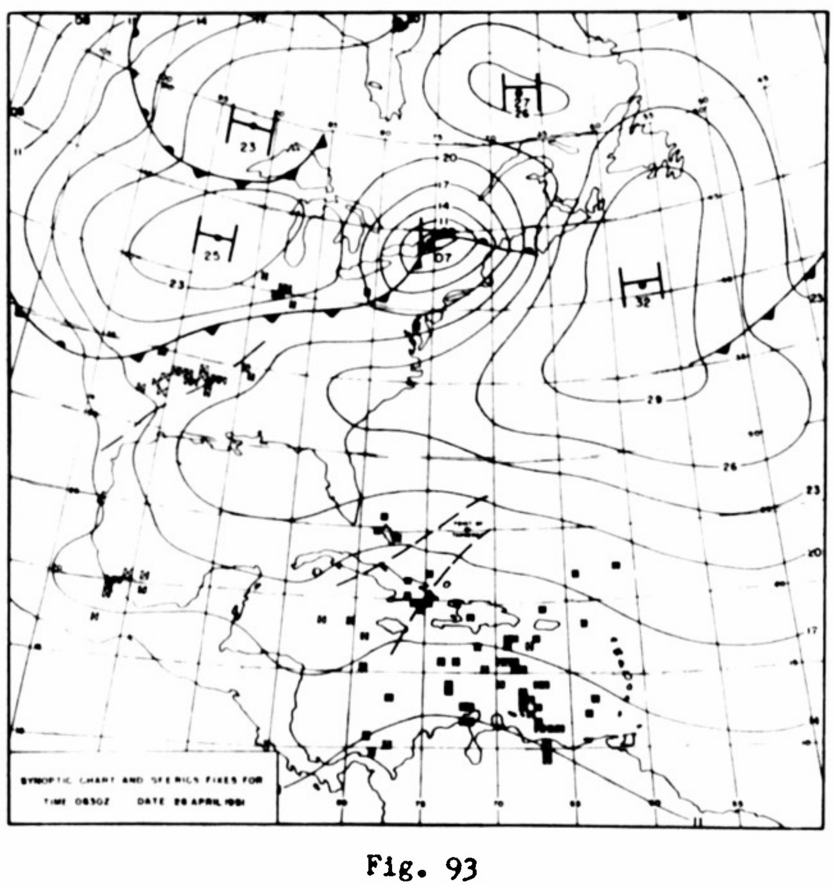

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 0630Z DATE 26 APRIL 1961

Fig. 93

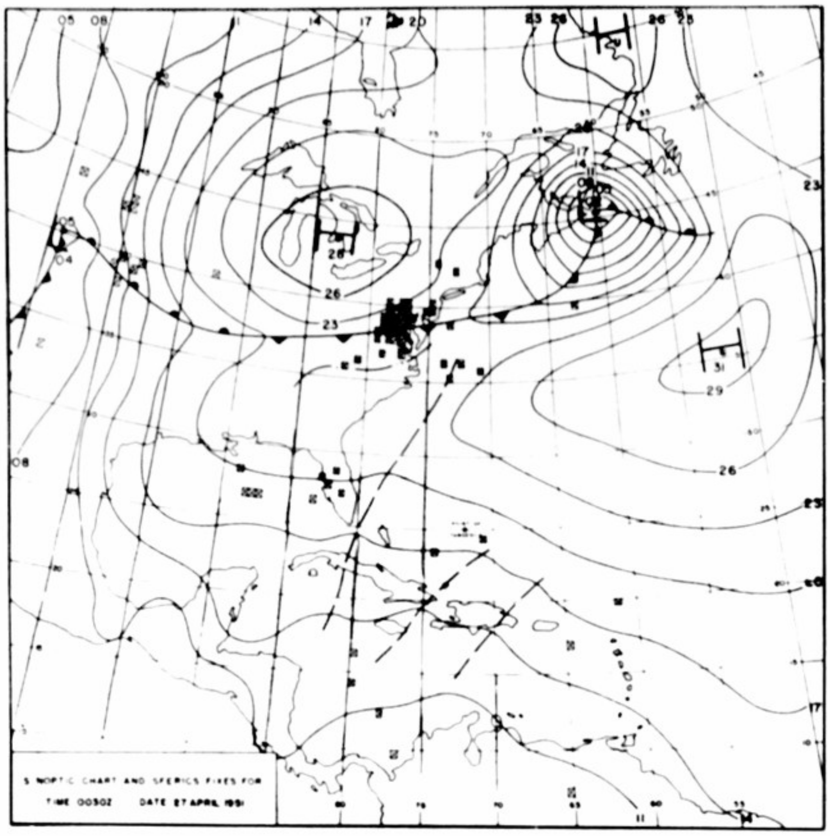

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 0030Z DATE 27 APRIL 1951

Fig. 94

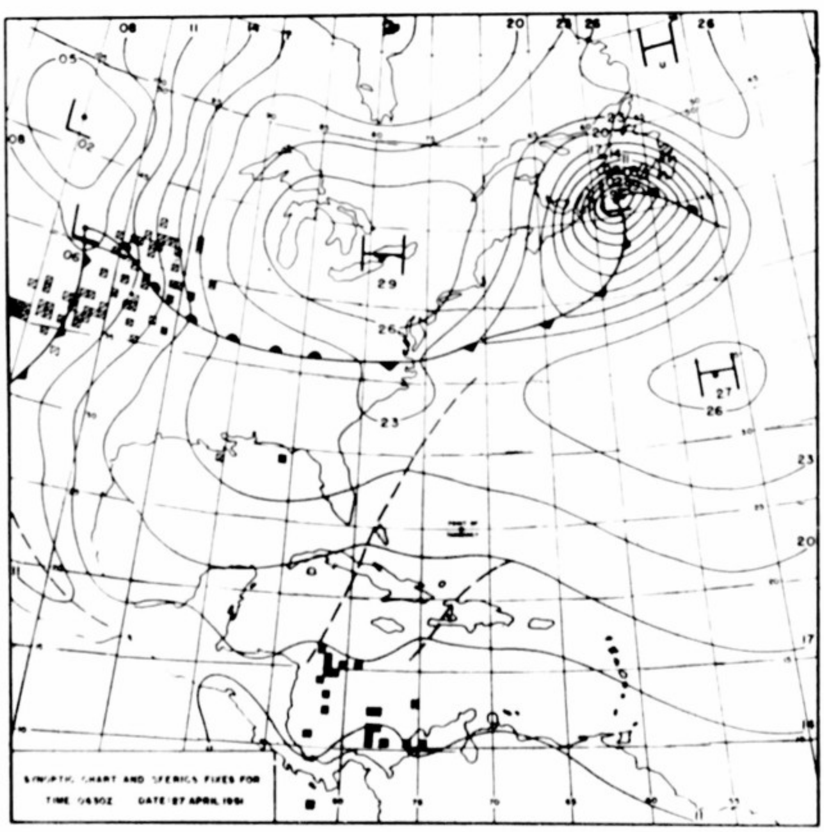

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 0630Z DATE 27 APRIL 1951

Fig. 95

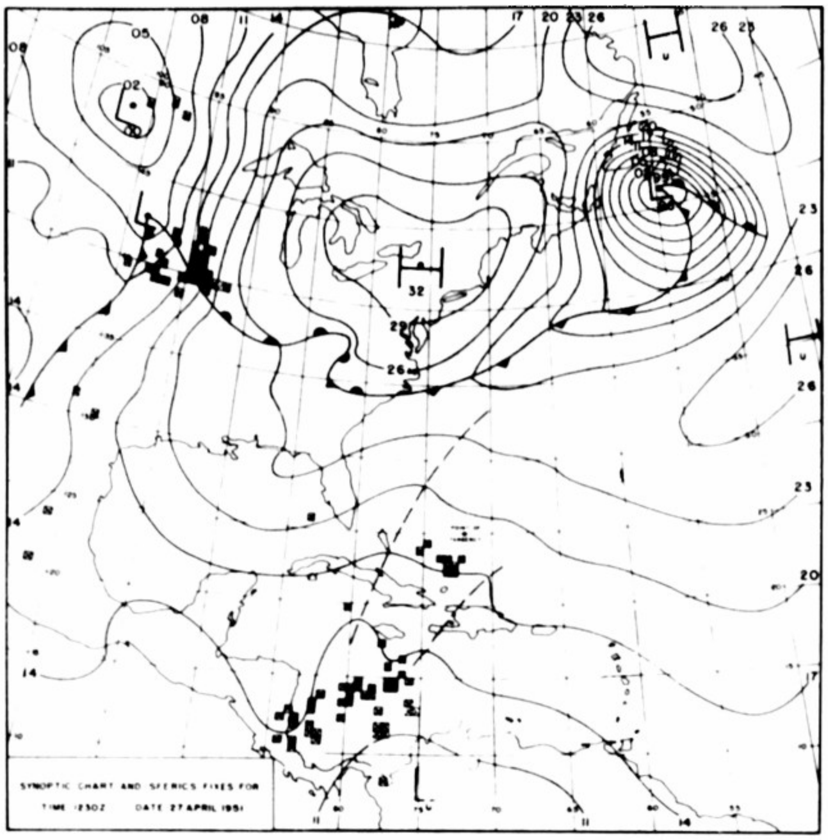

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 1230Z DATE 27 APRIL 1951

Fig. 96

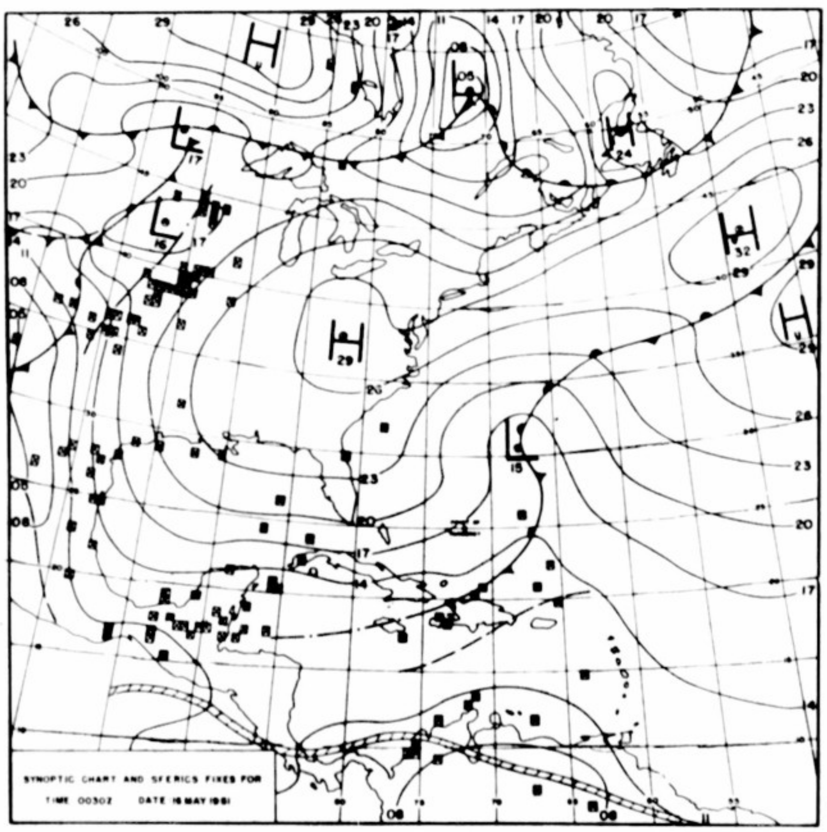

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 0030Z DATE 16 MAY 1951

Fig. 97

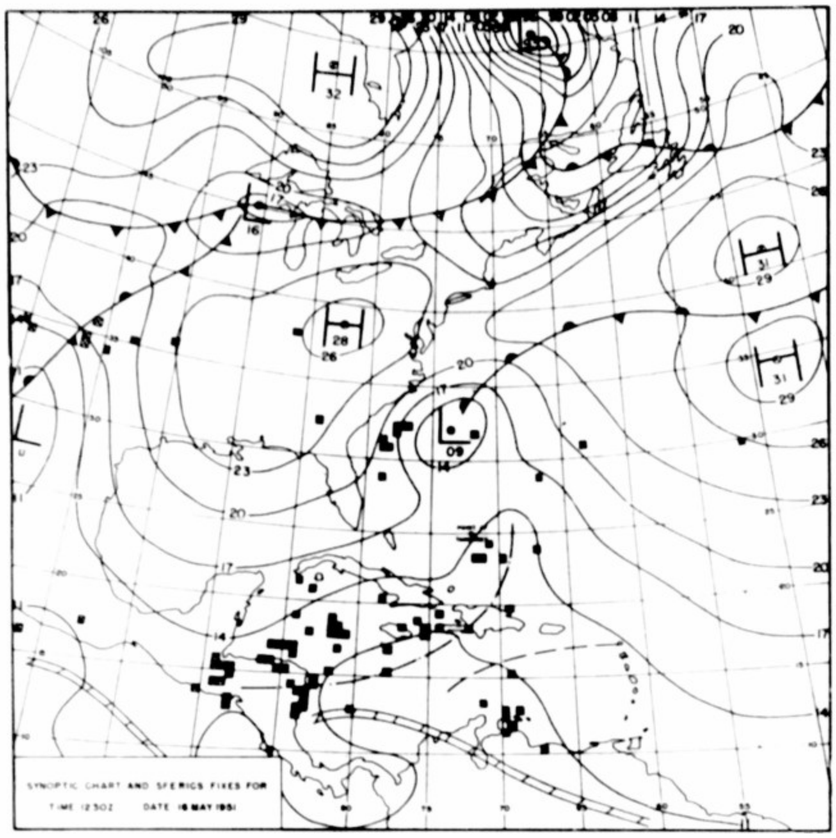

SYNOPTIC CHART AND SFERICS FIXES FOR
TIME 1230Z DATE 16 MAY 1961

Fig. 98

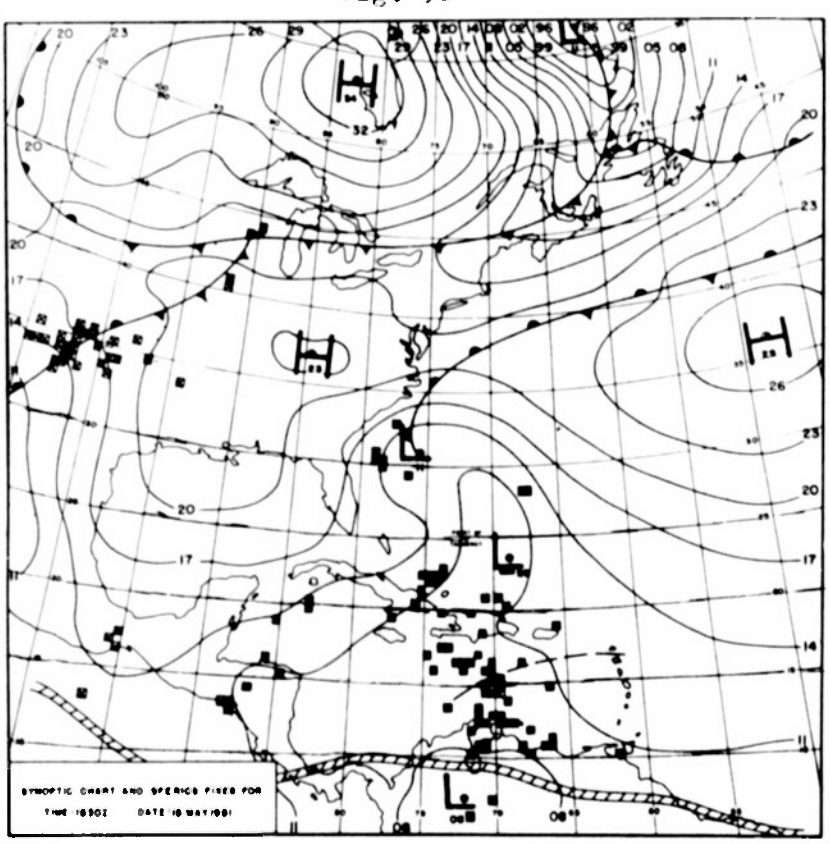

SYNOPTIC CHART AND SFERICS FIXES FOR
DATE 16 MAY 1961

Fig. 99

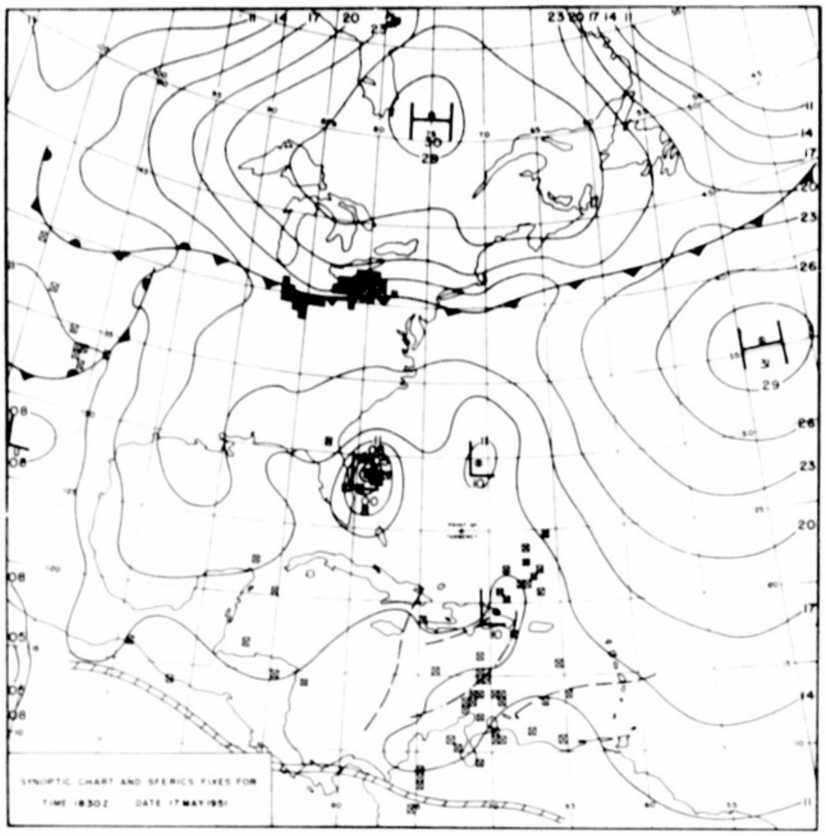


Fig. 100

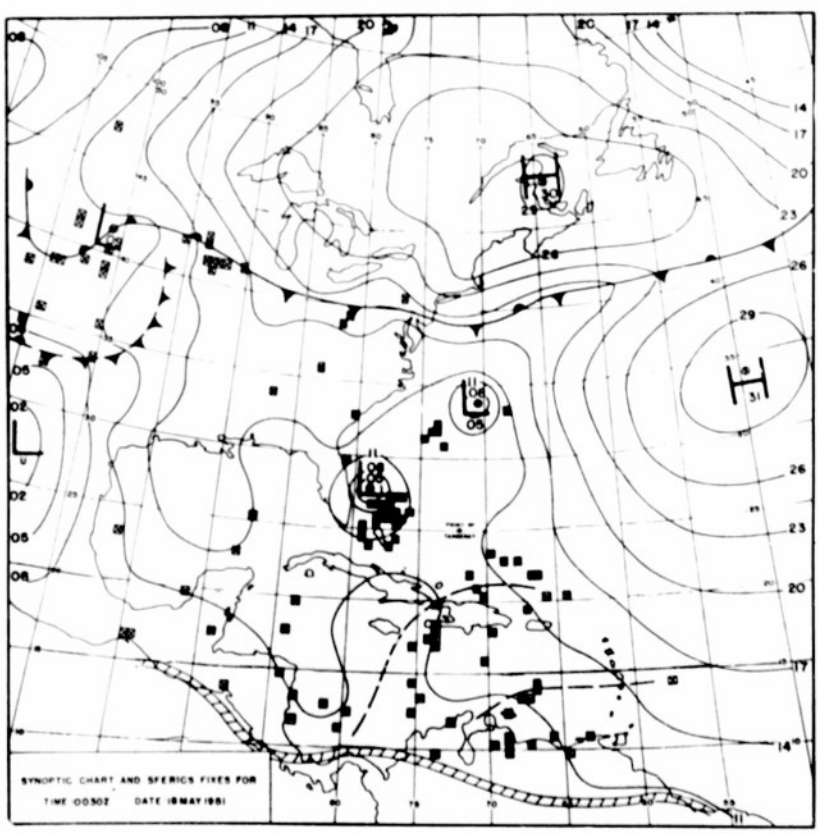


Fig. 101

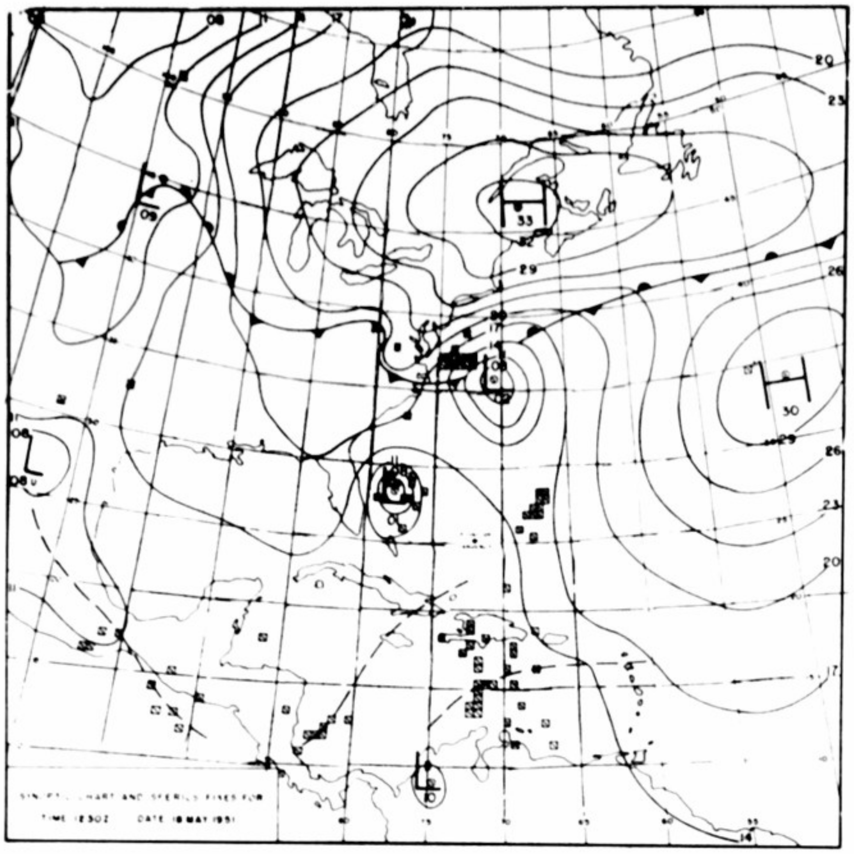


Fig. 102

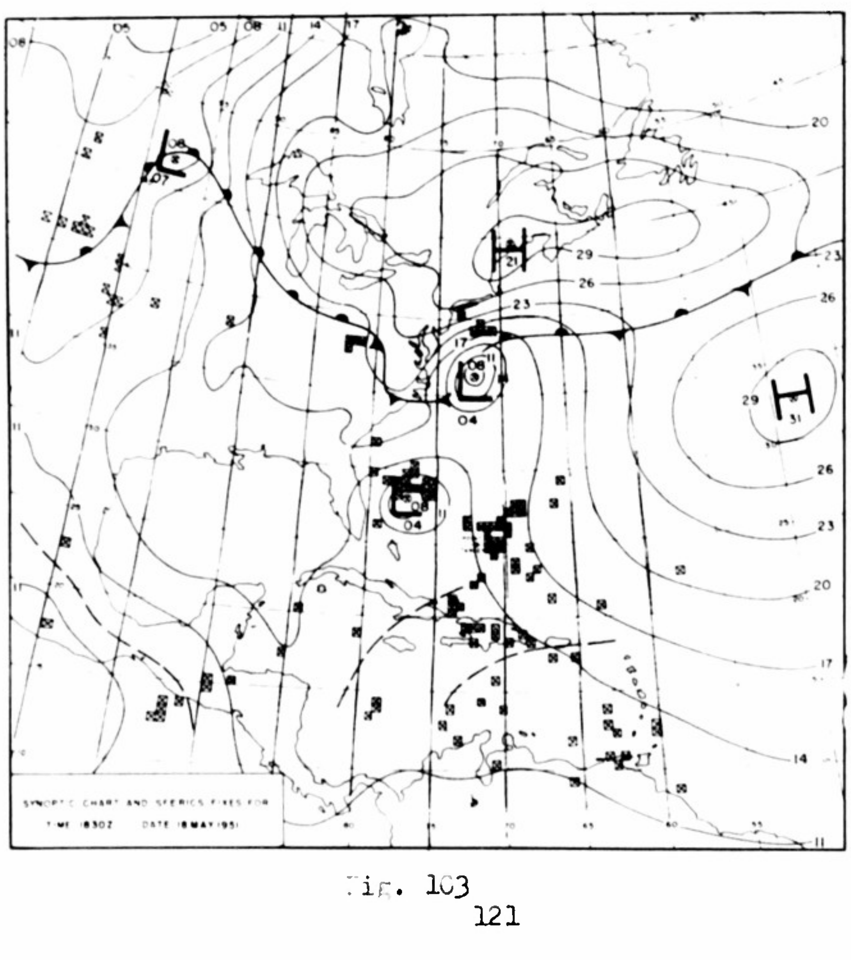


Fig. 103

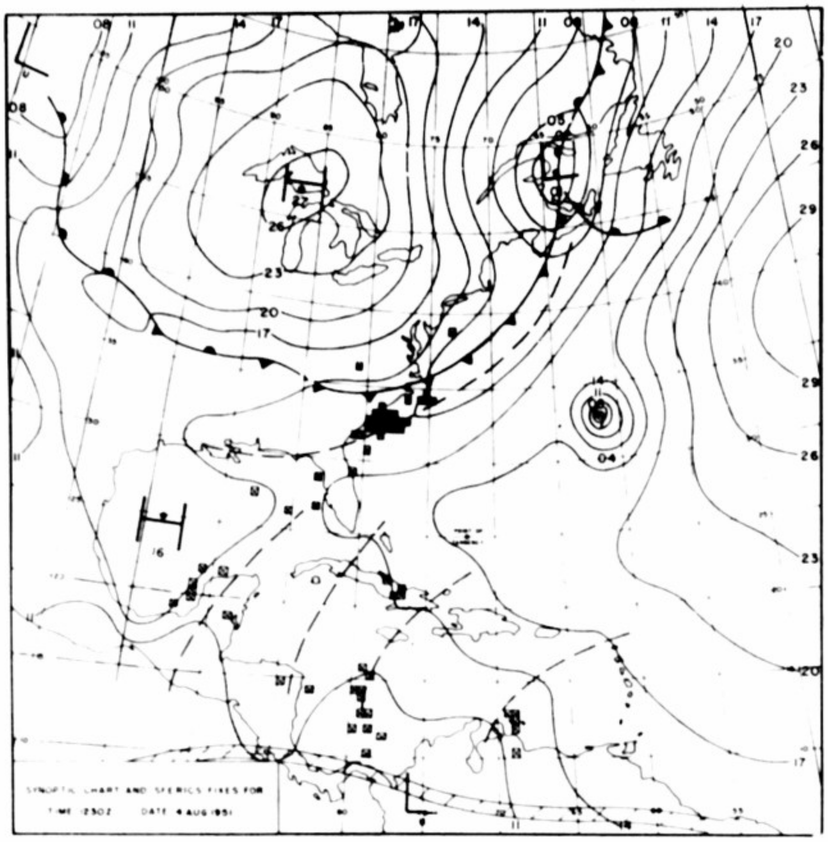


Fig. 104

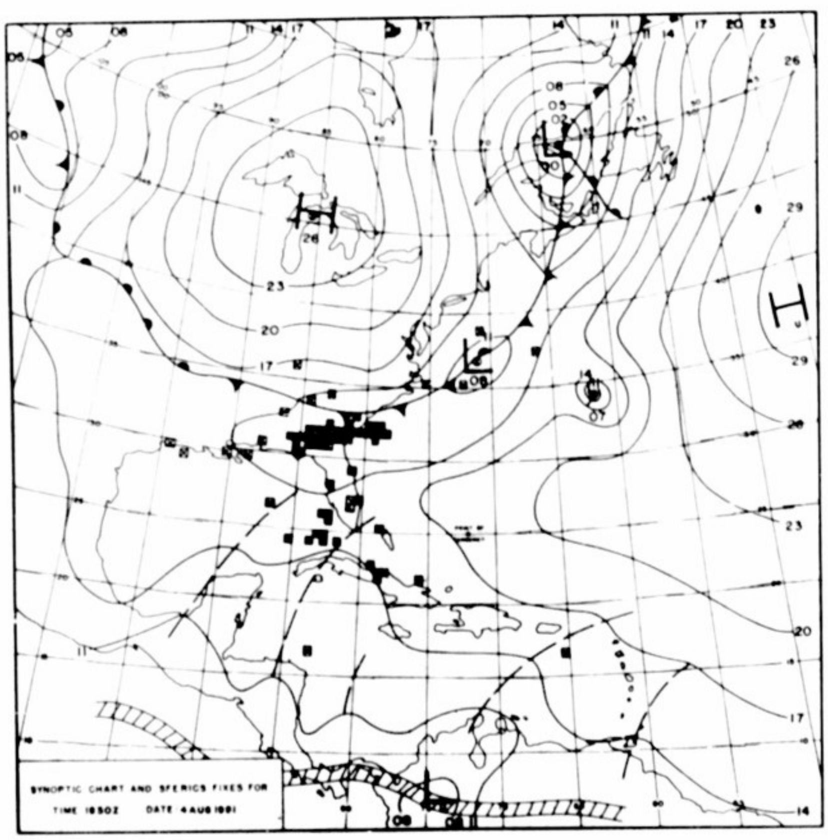


Fig. 105

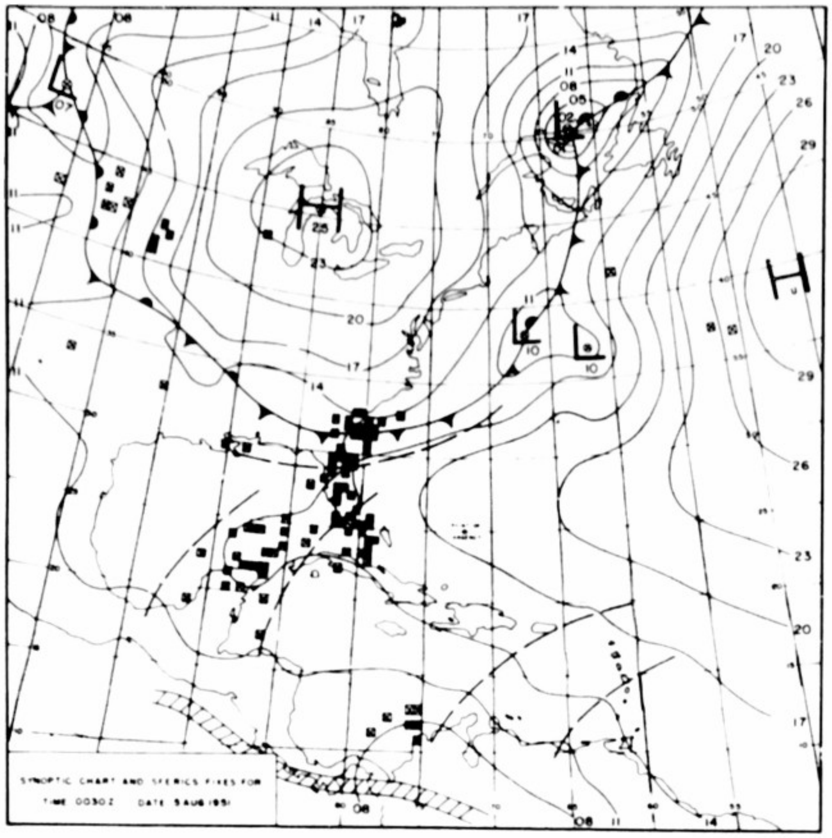


Fig. 106

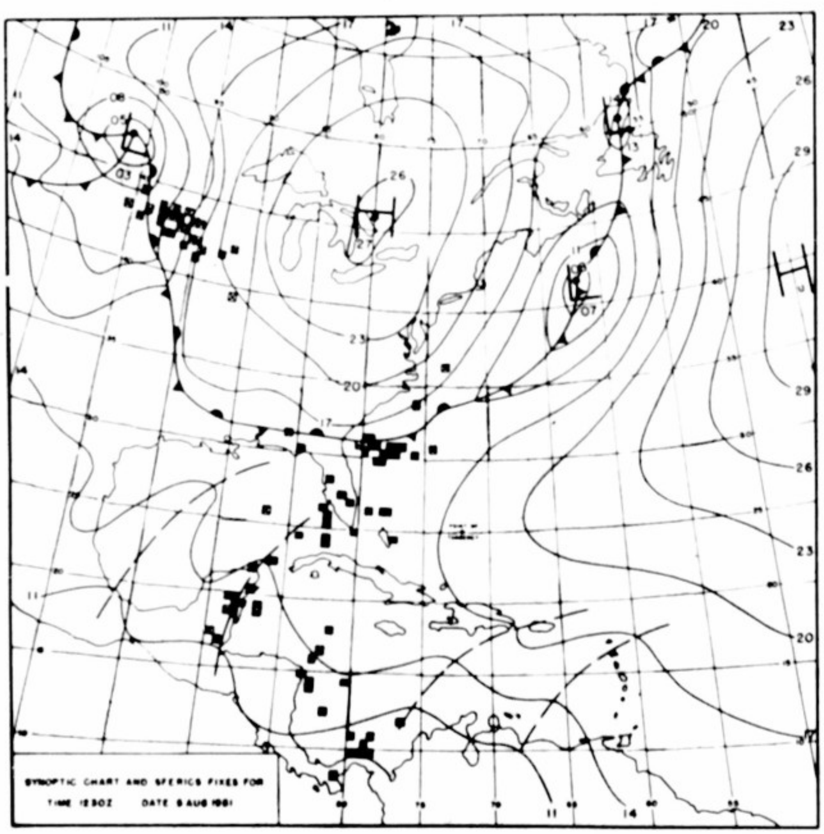


Fig. 107

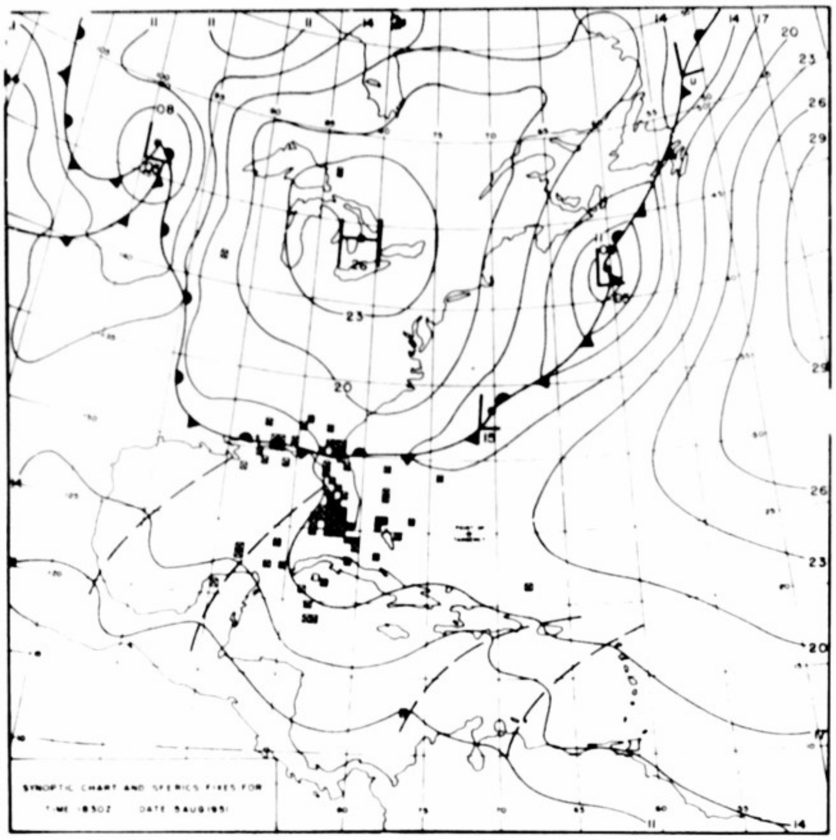


Fig. 108

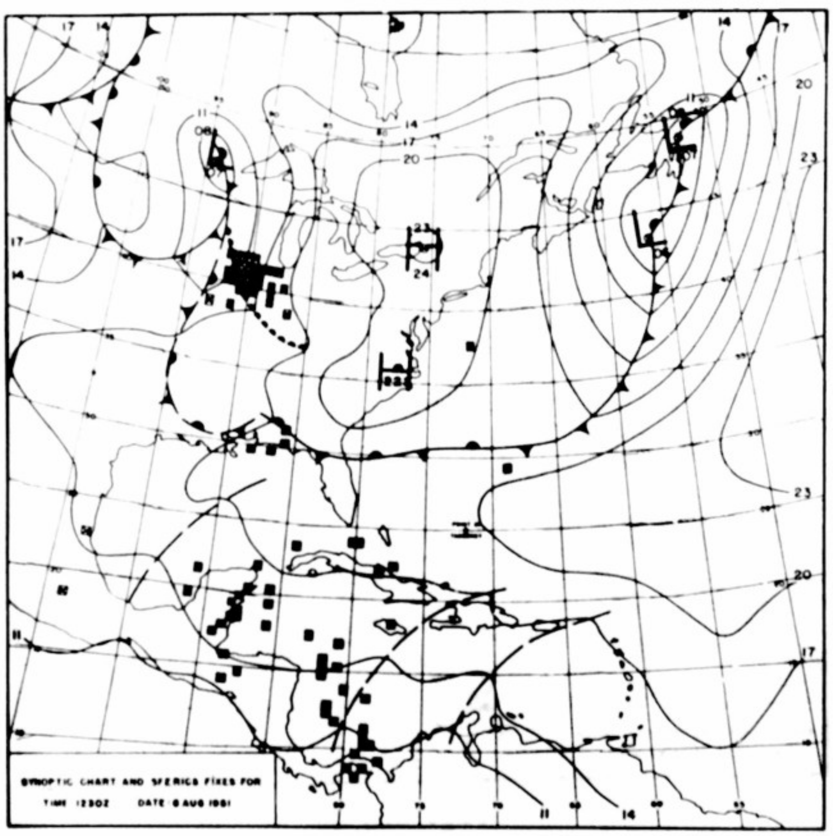
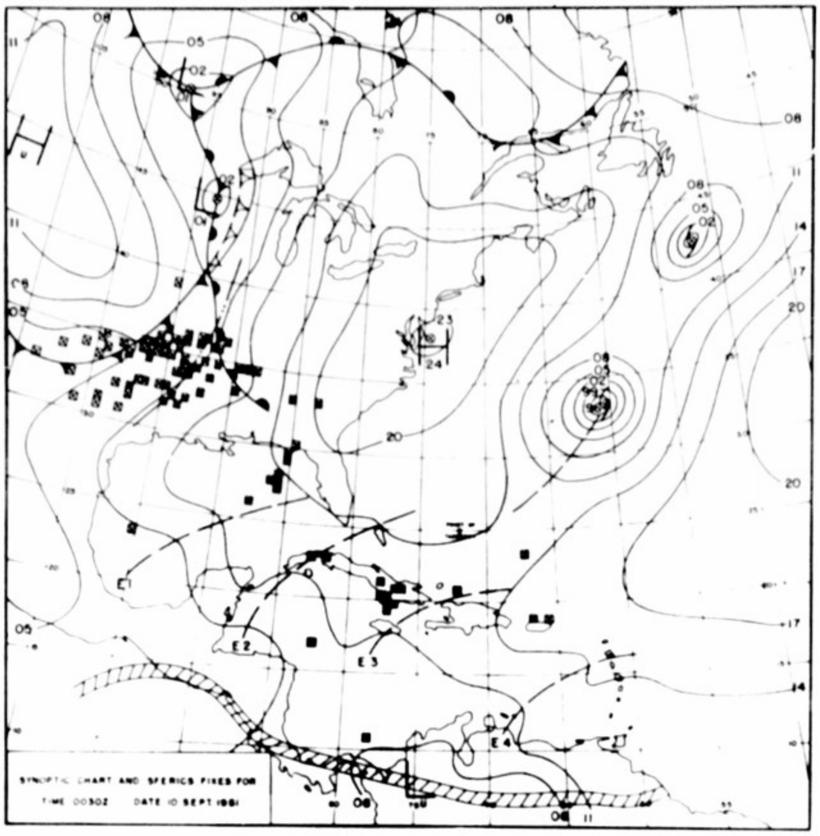


Fig. 109



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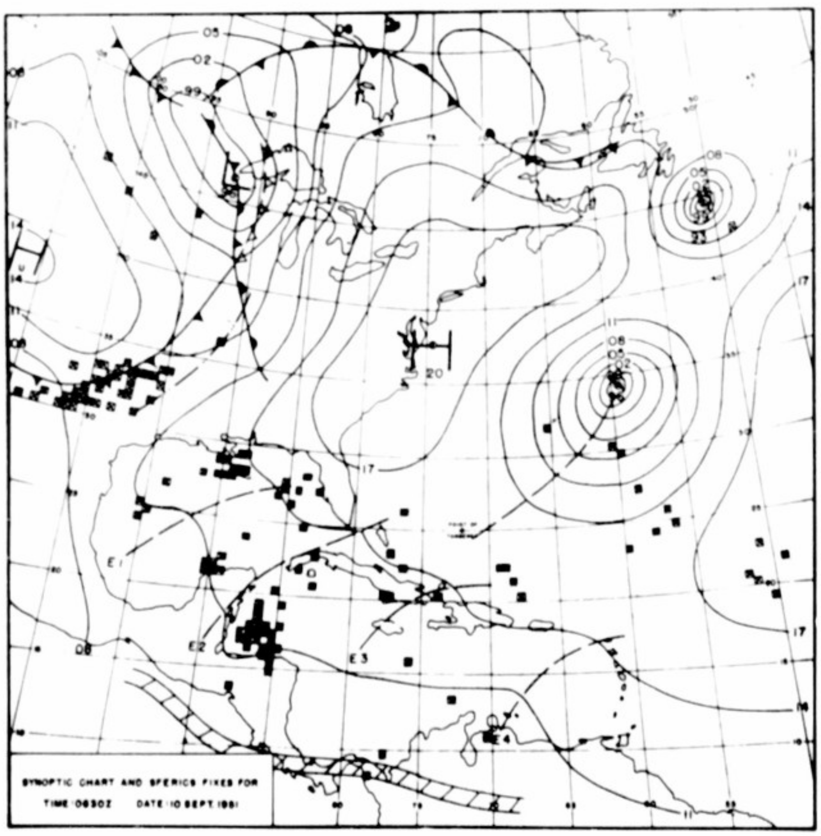

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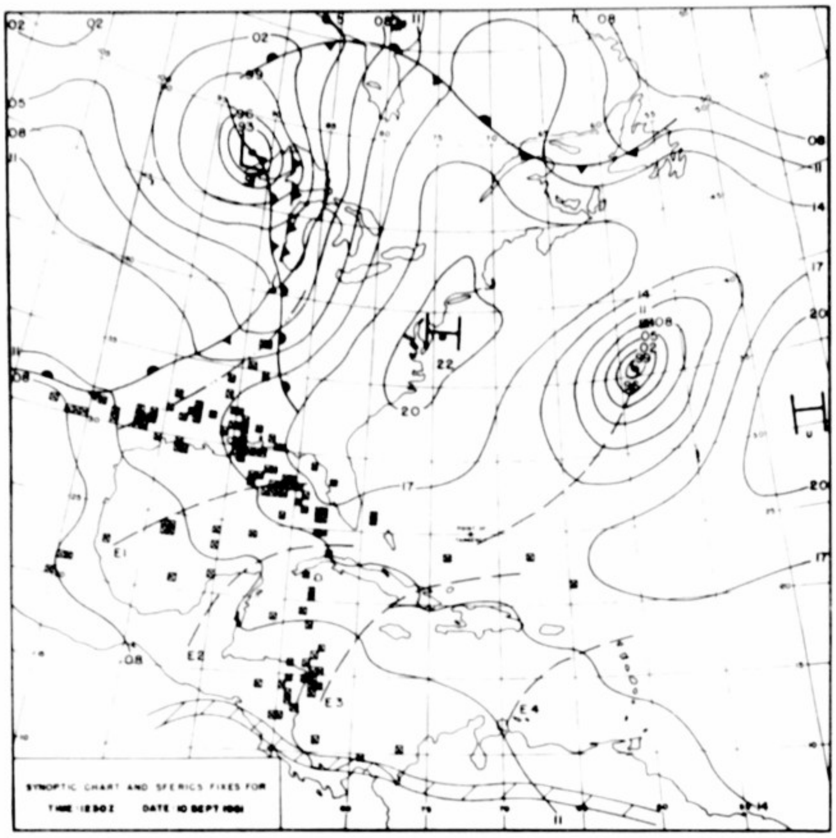

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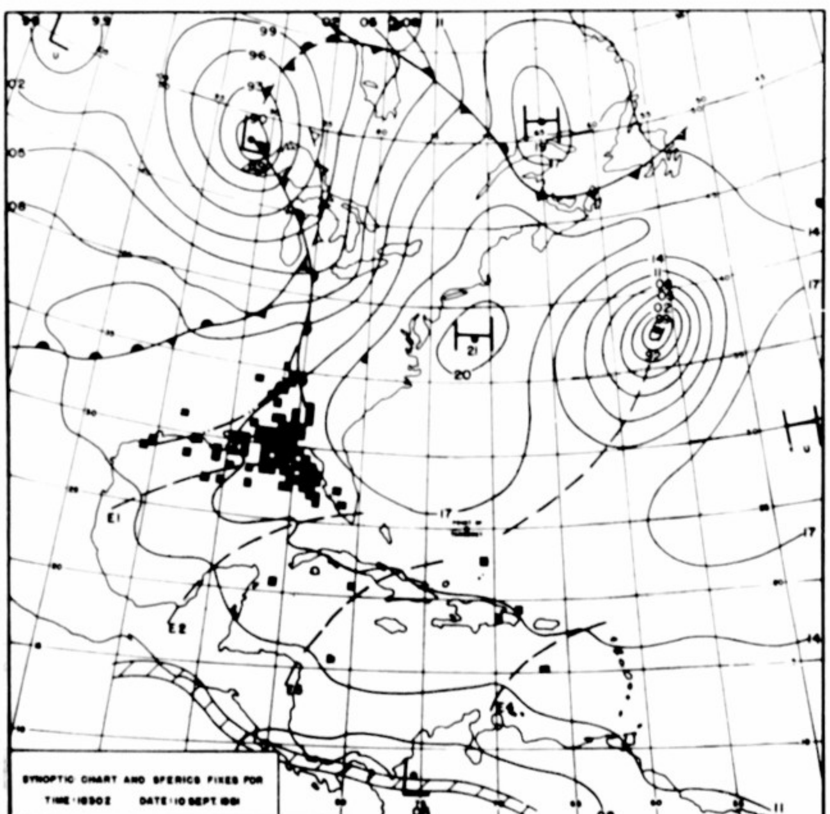

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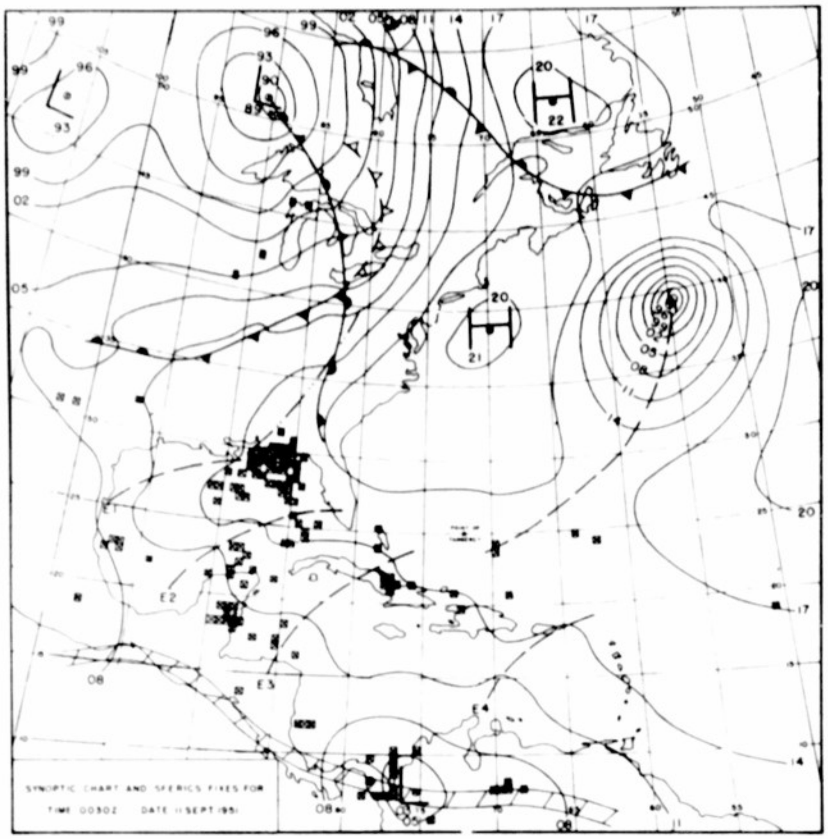

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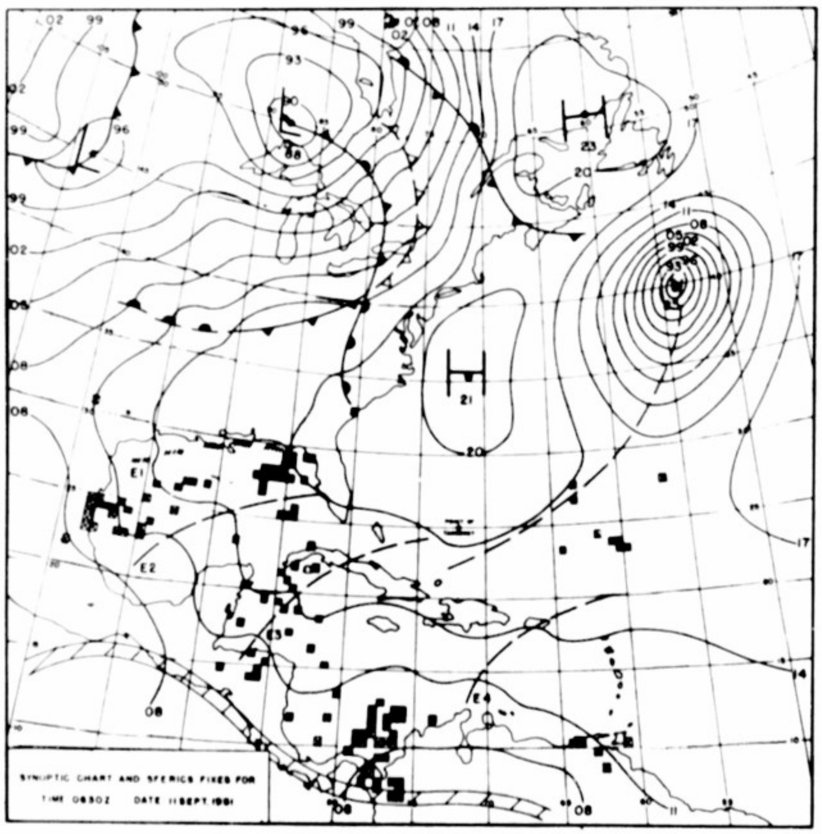

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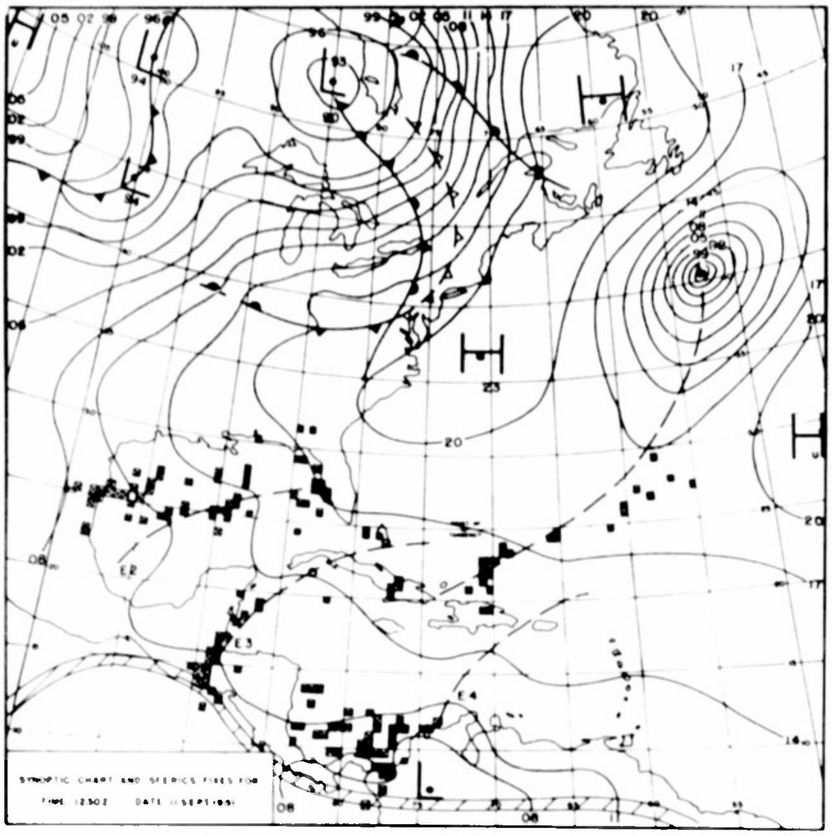

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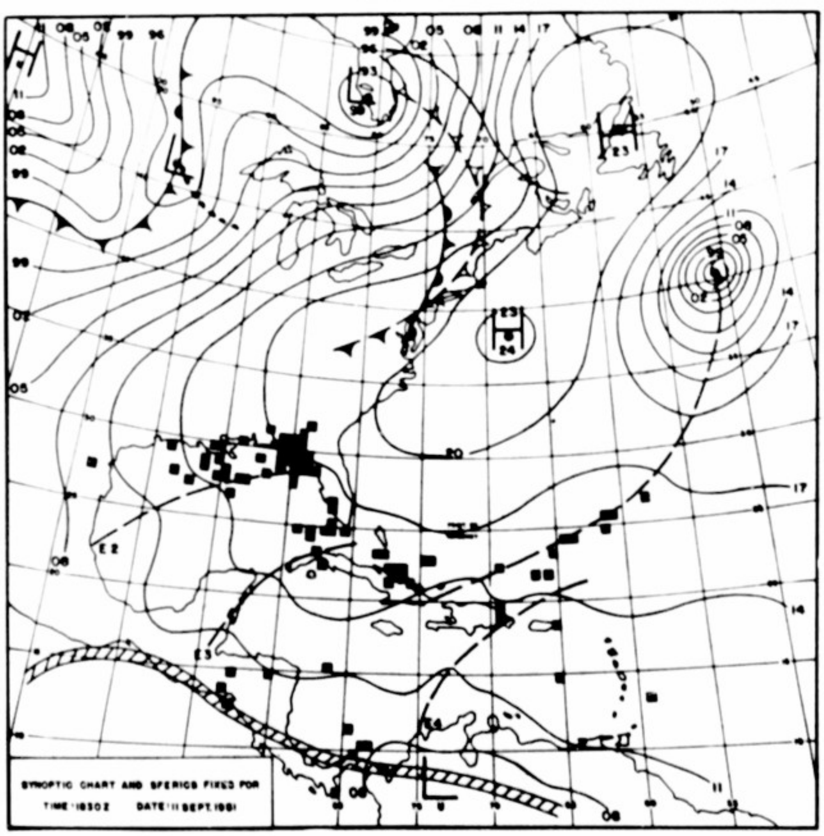

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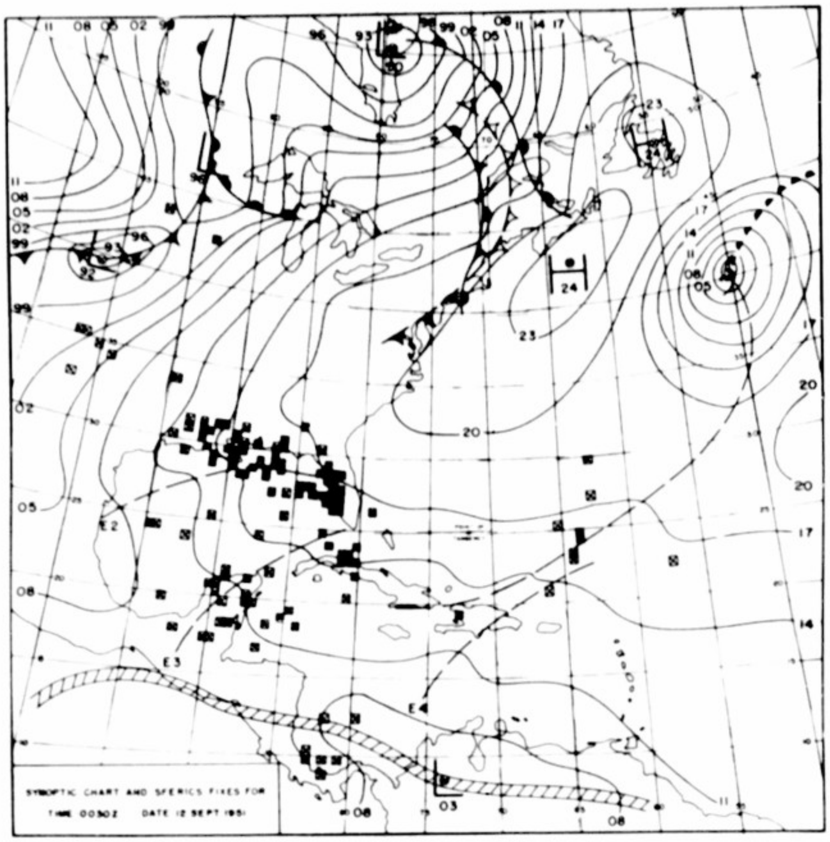

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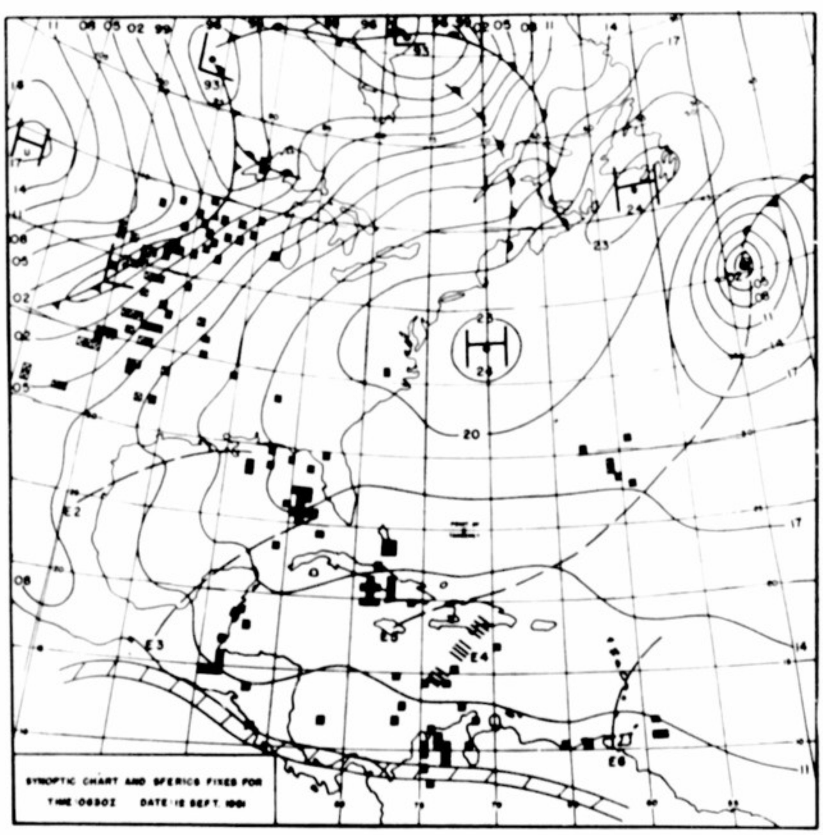

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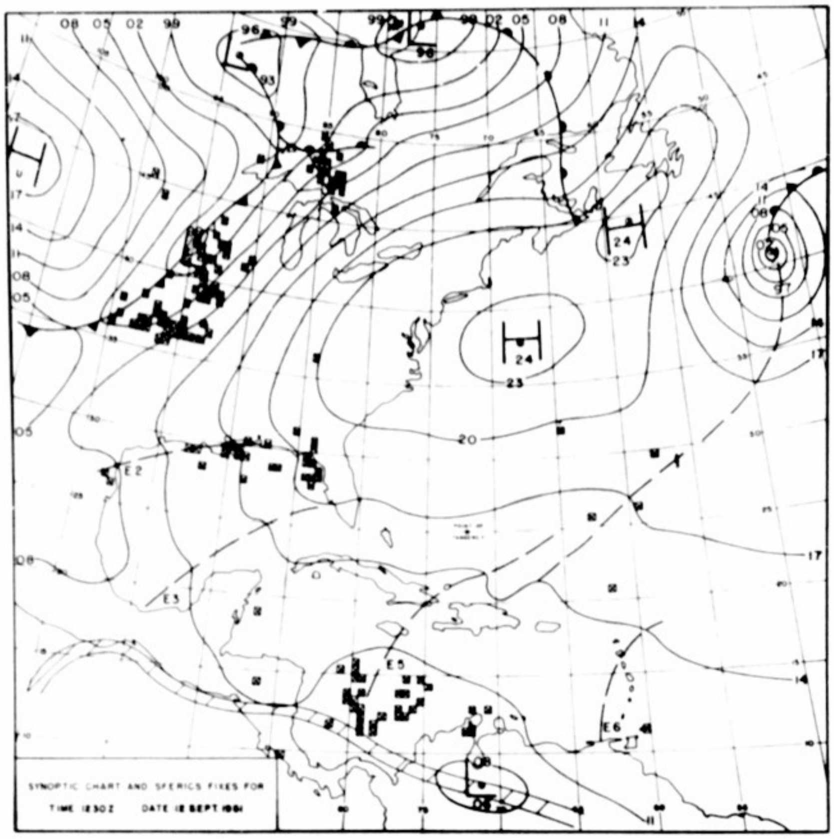

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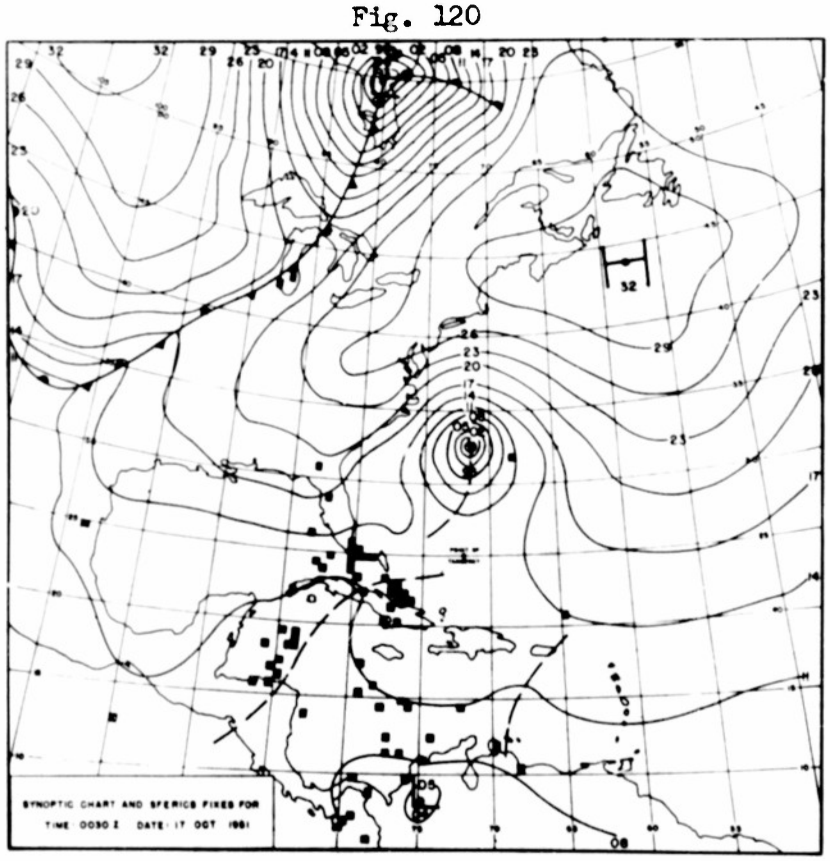

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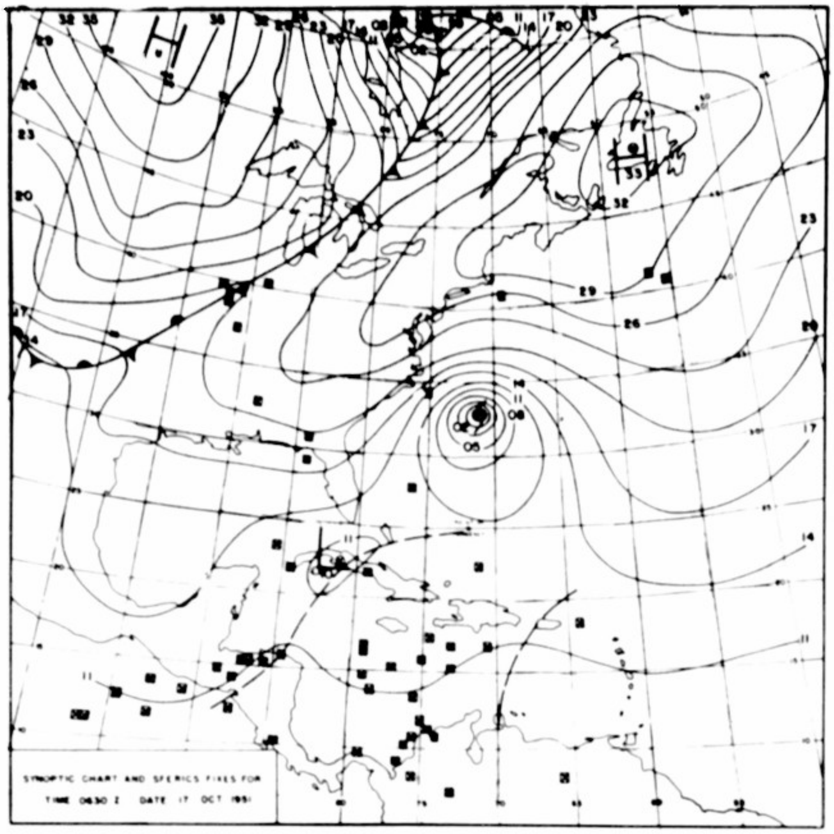

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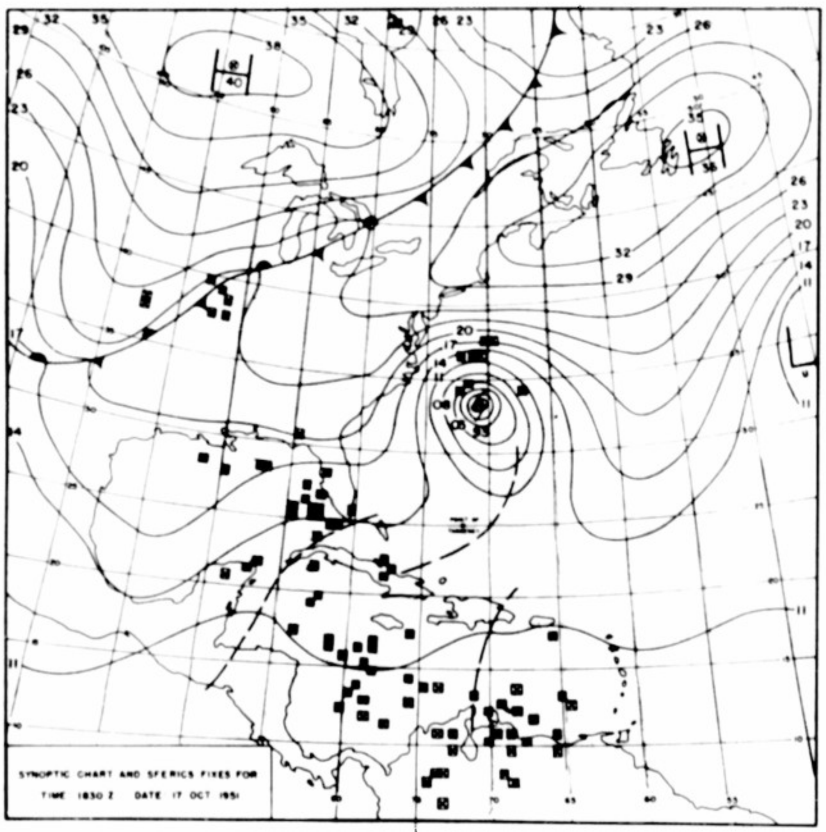

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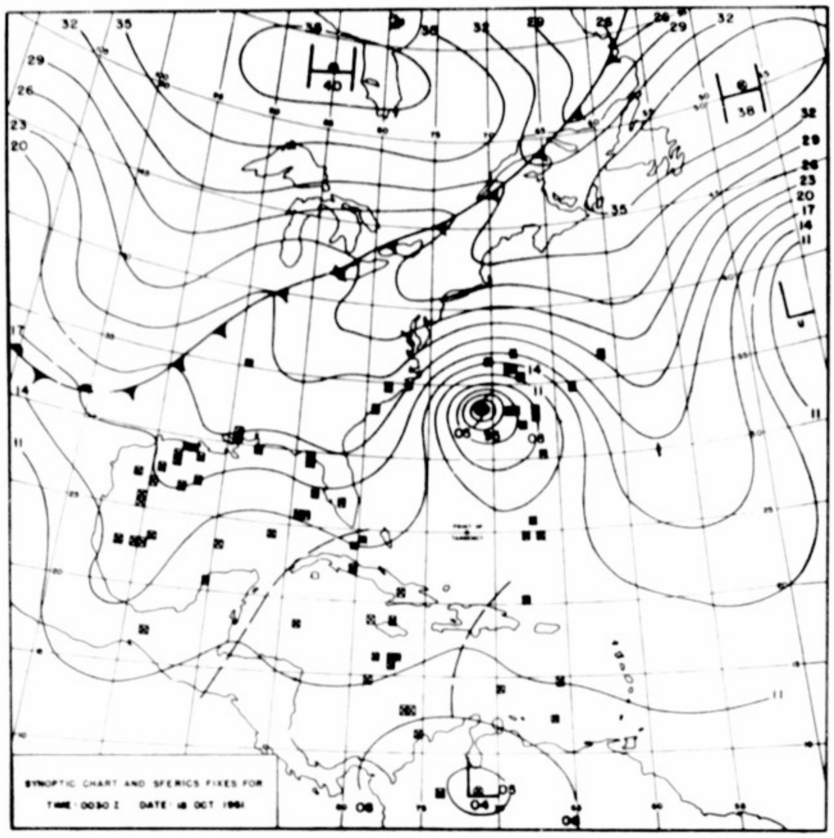

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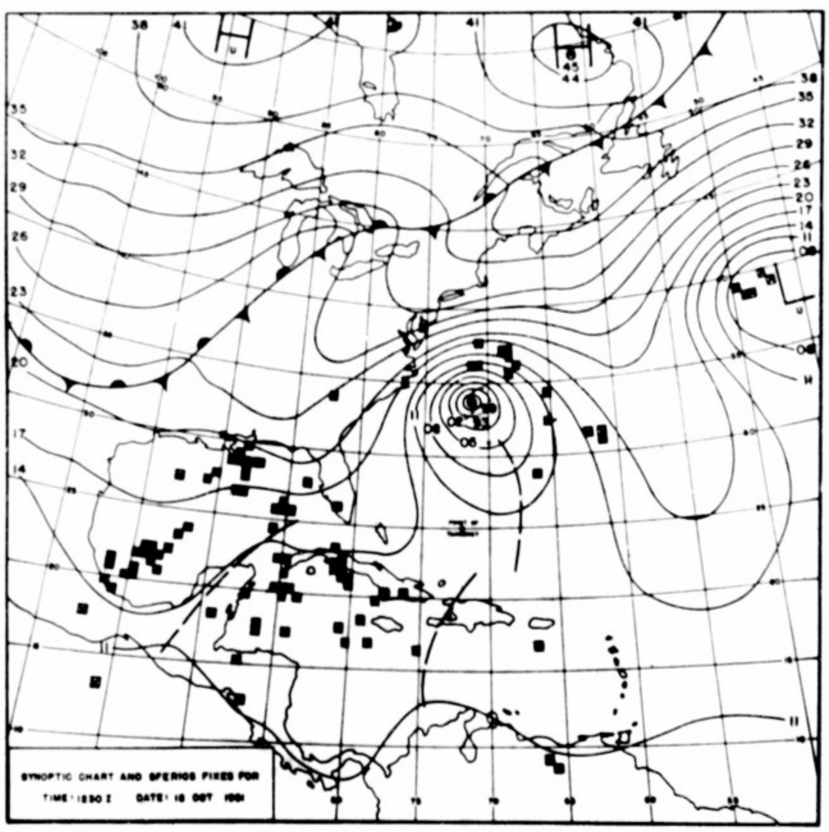

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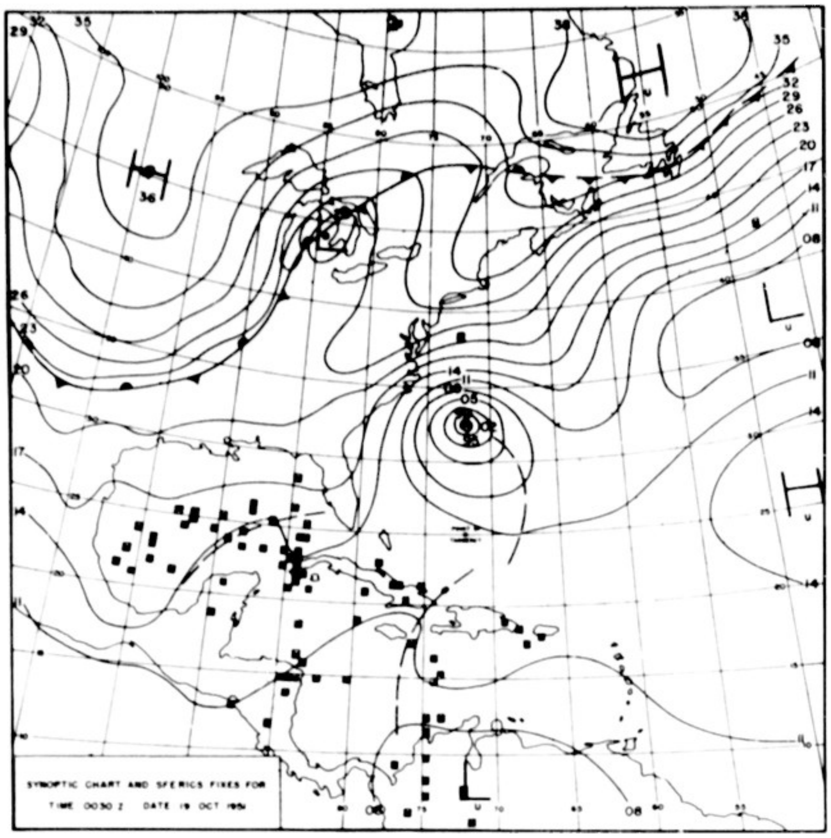

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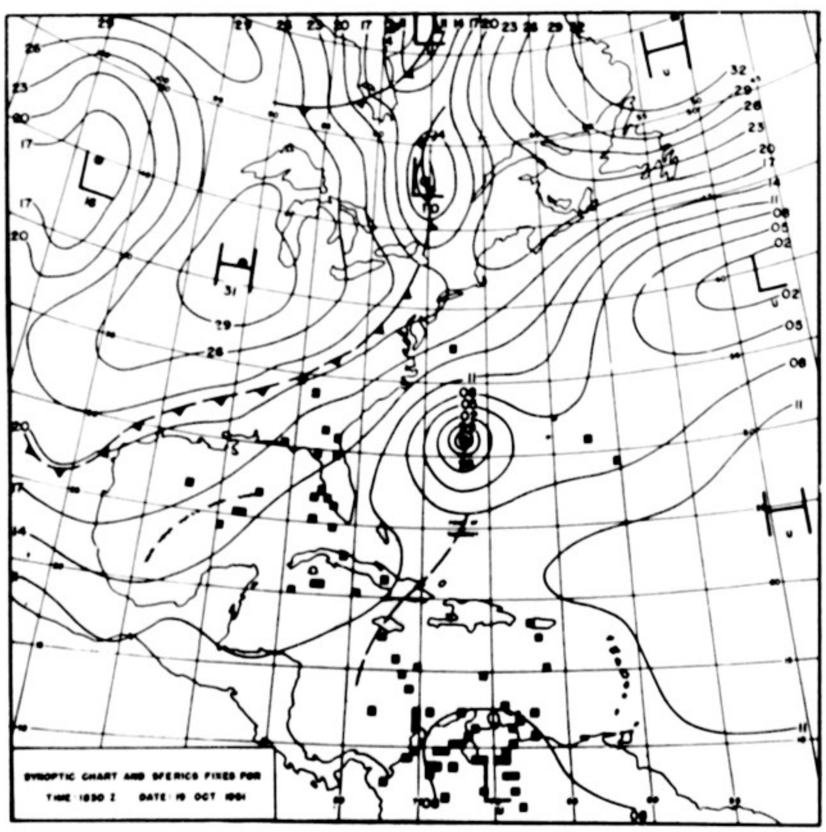

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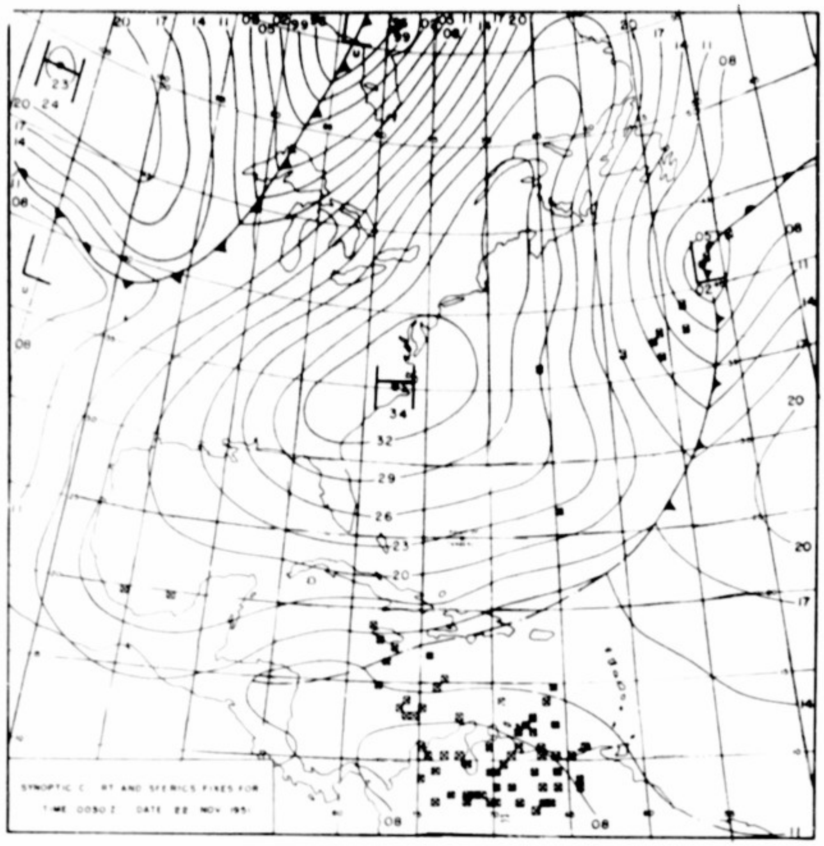

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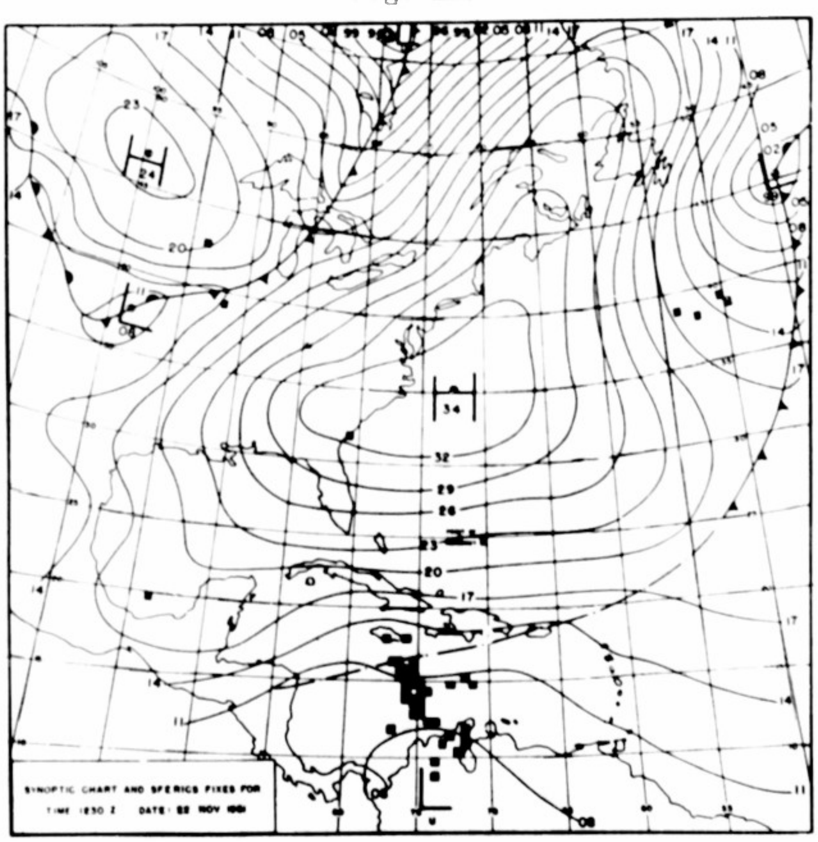

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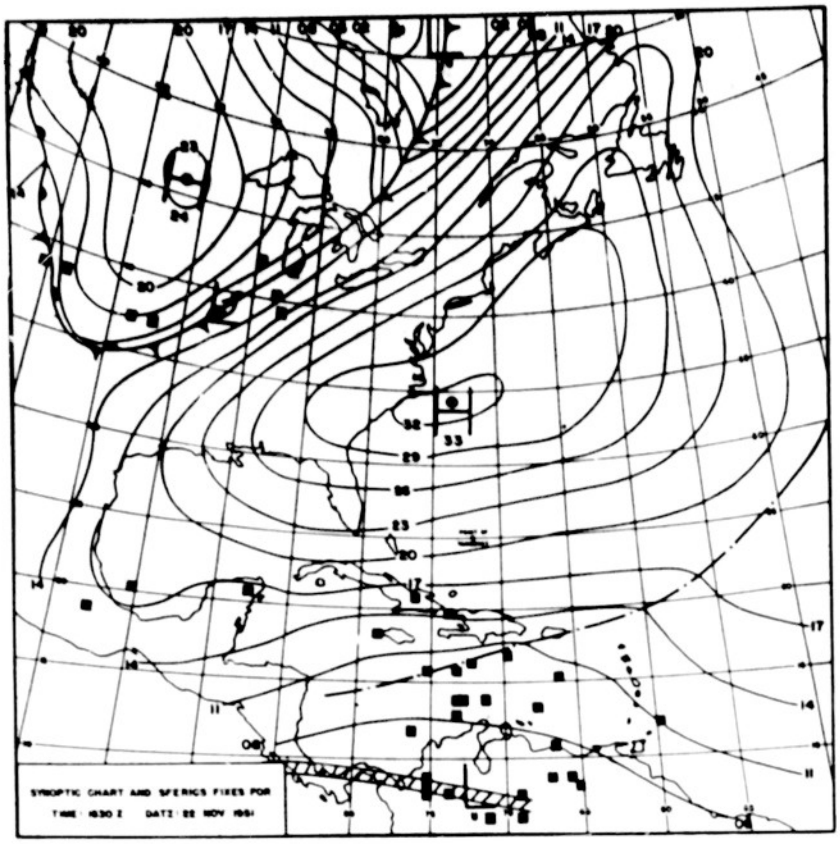

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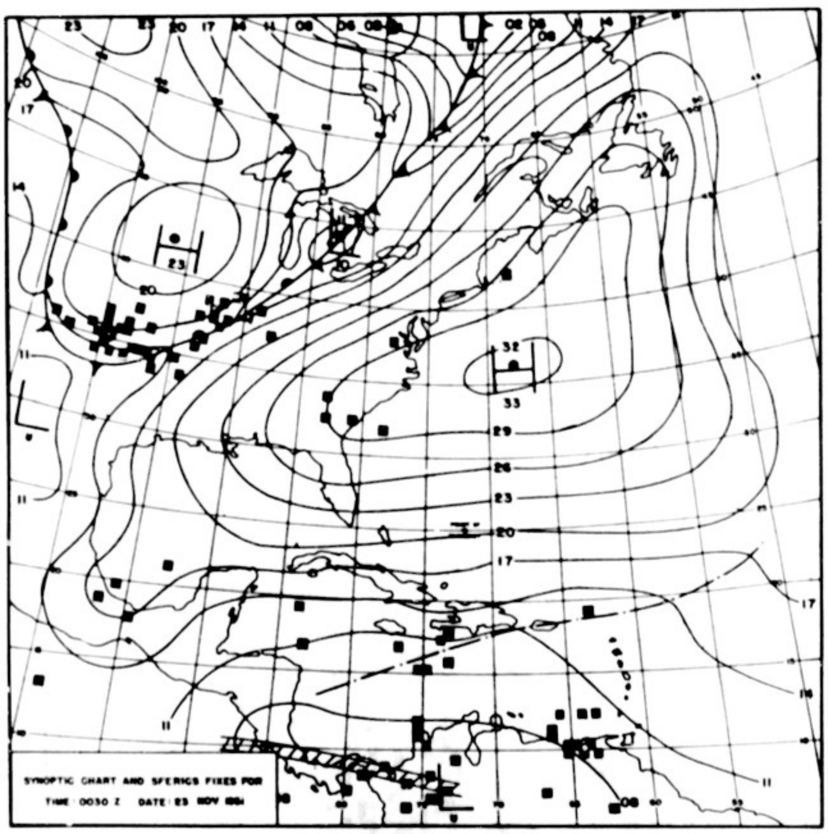

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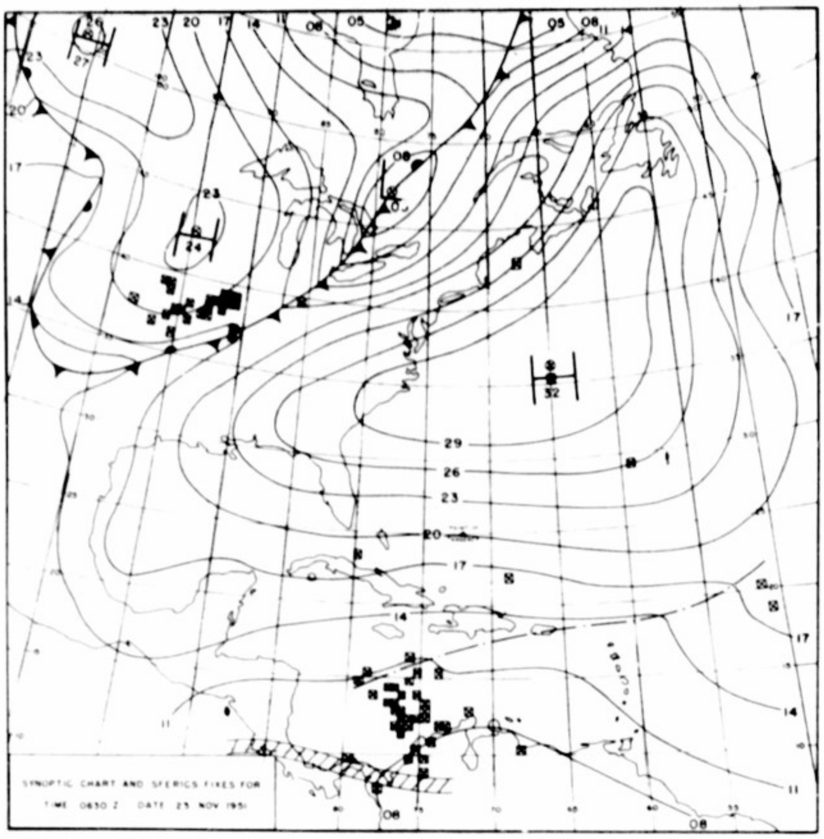

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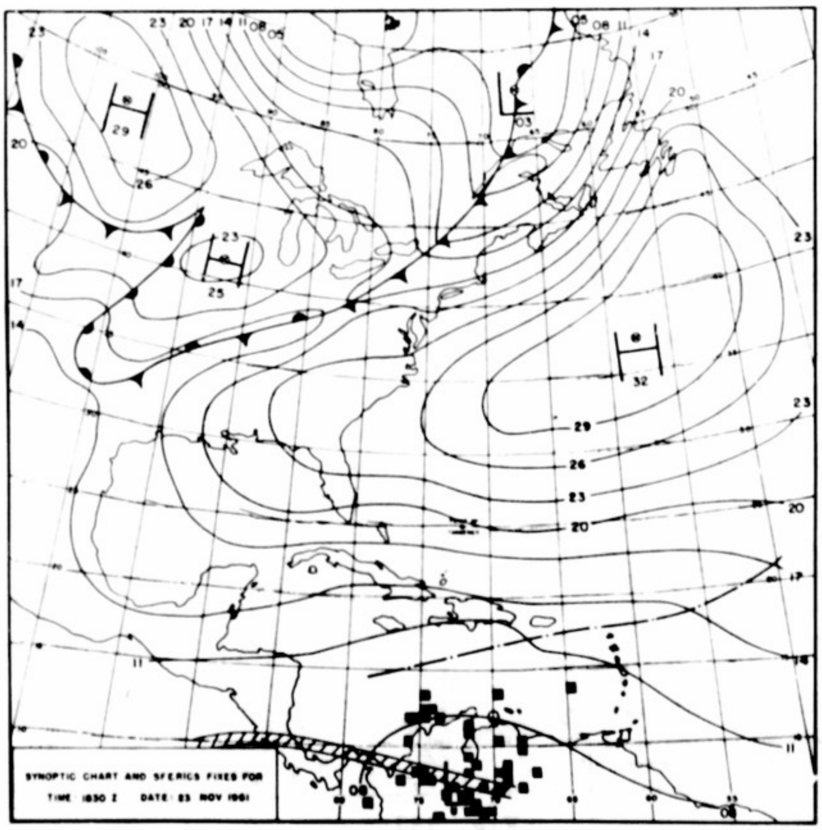

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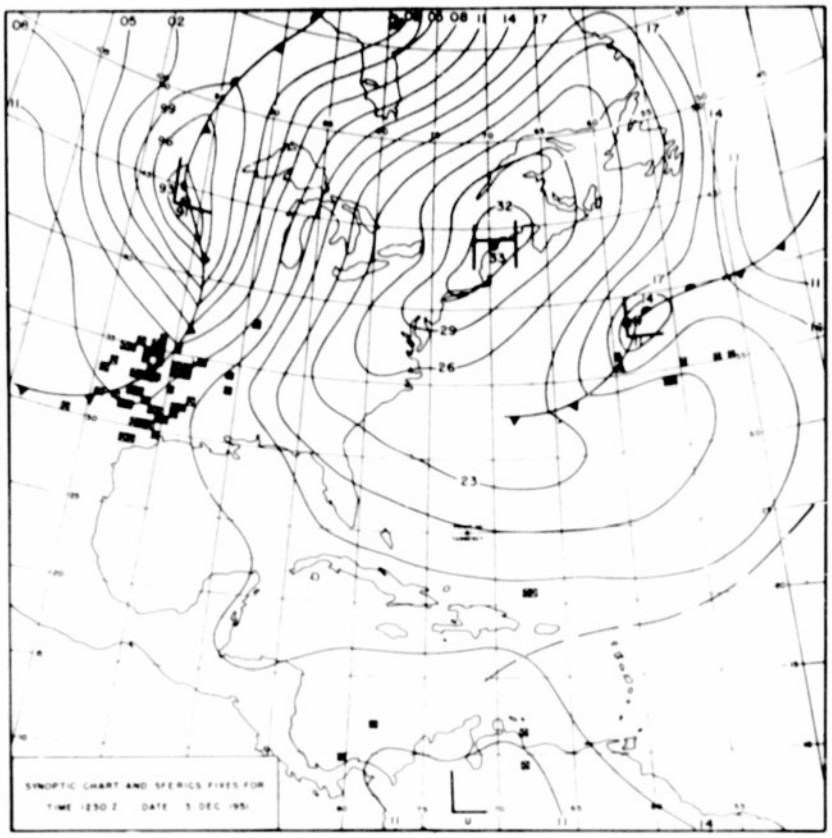

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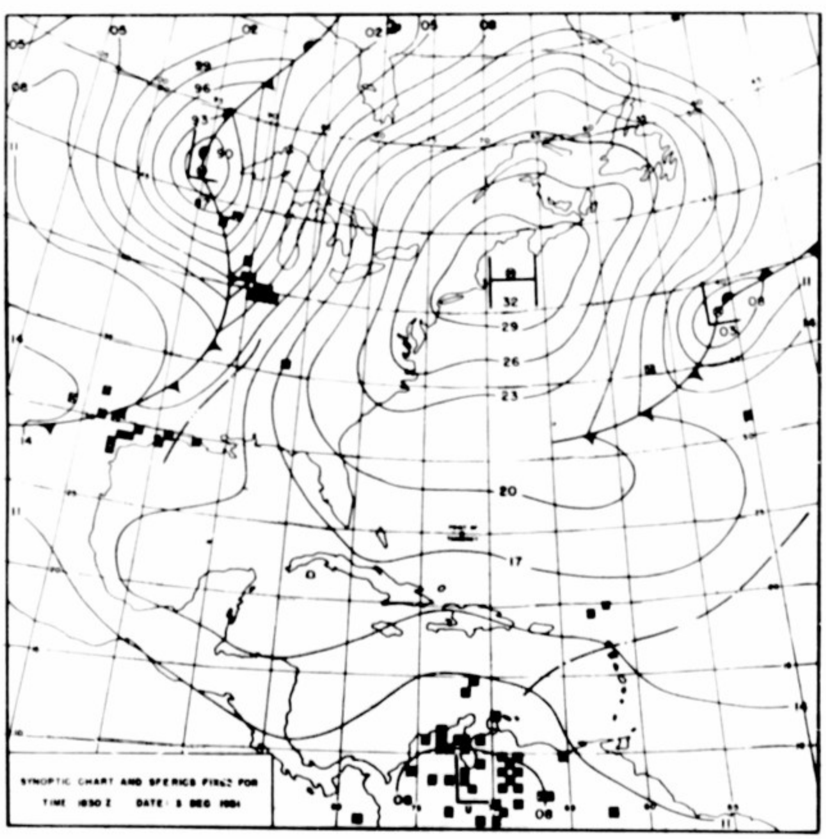

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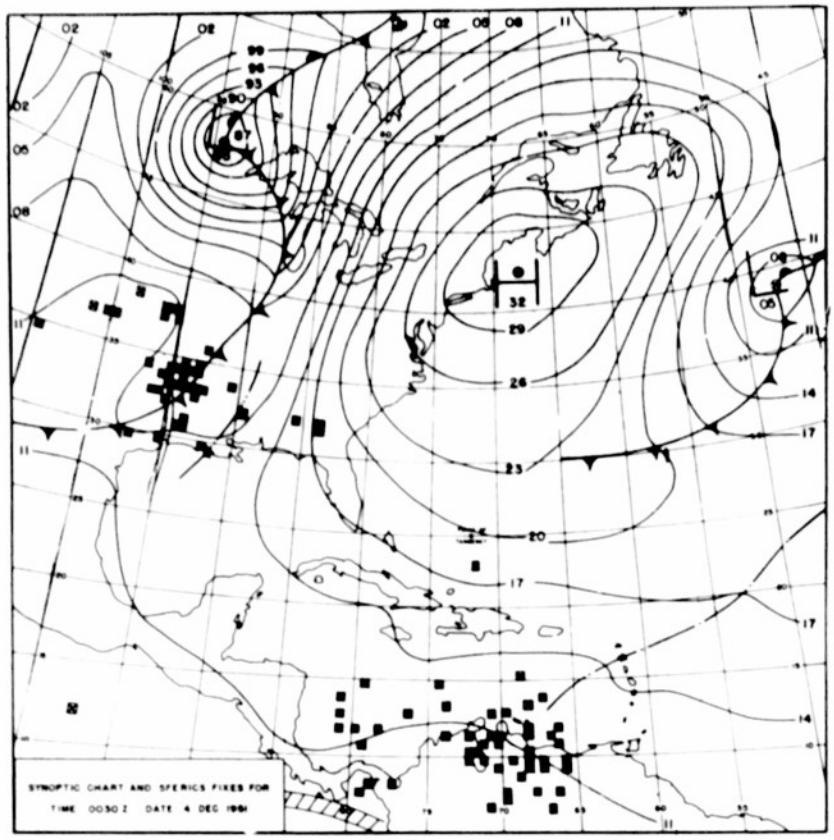

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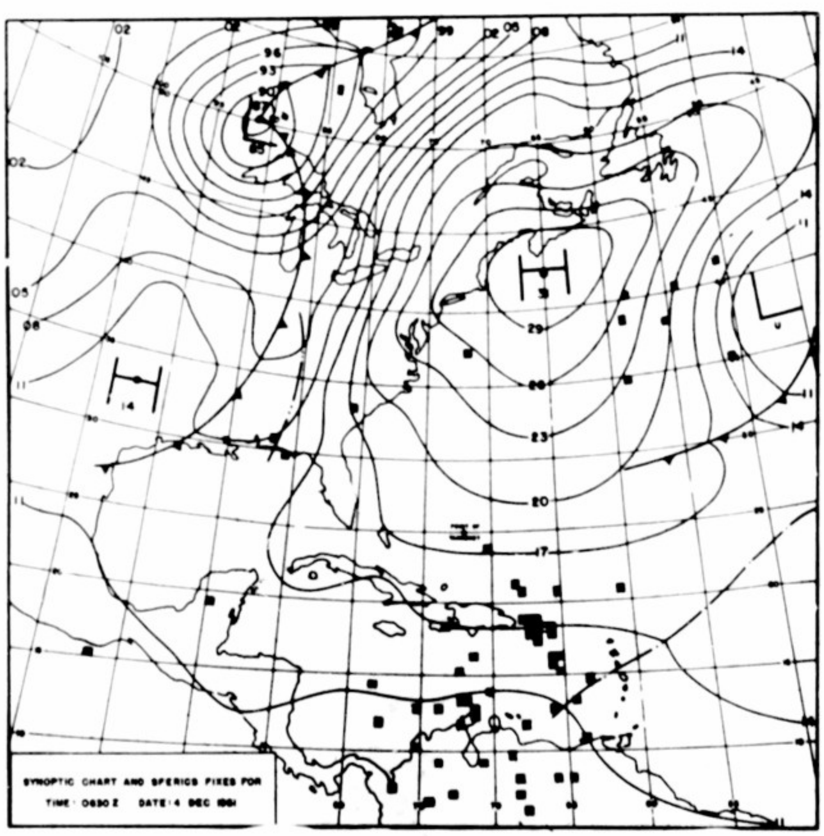

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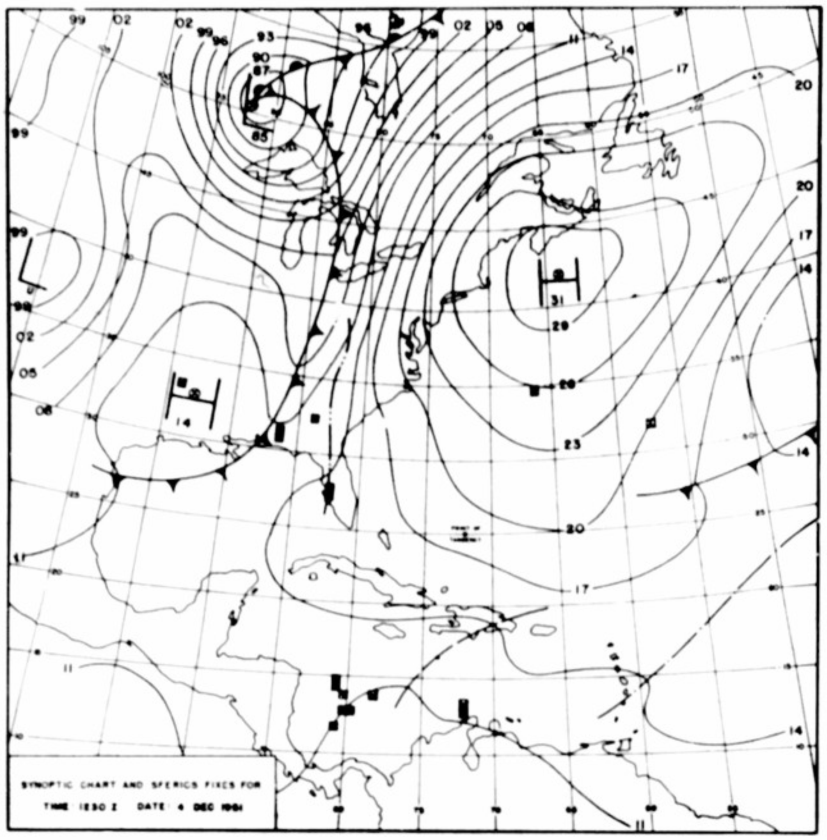

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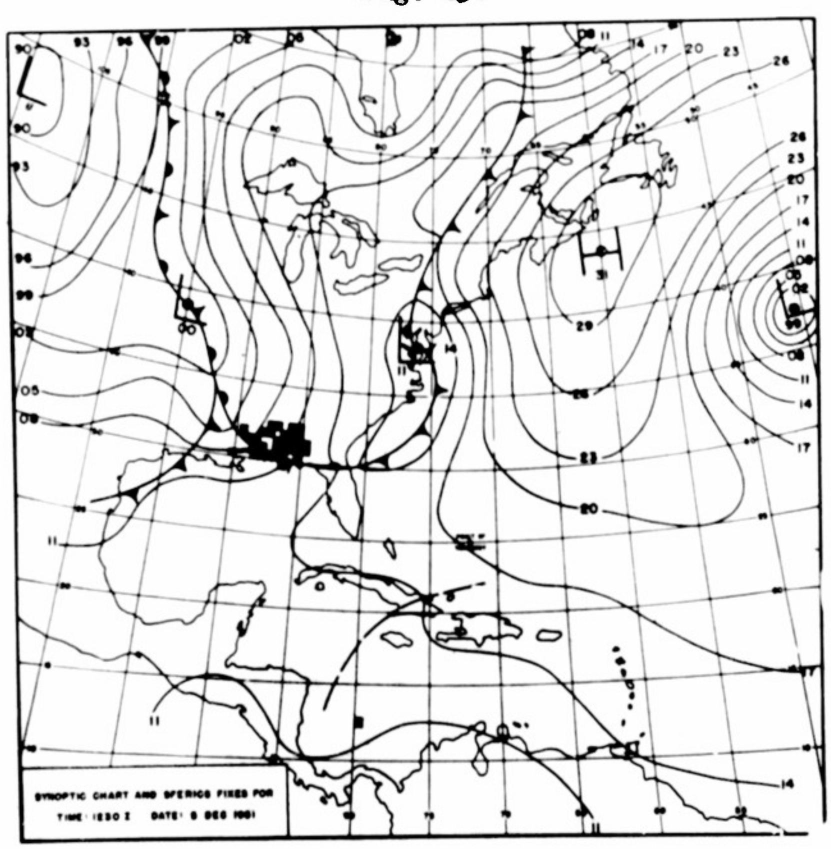

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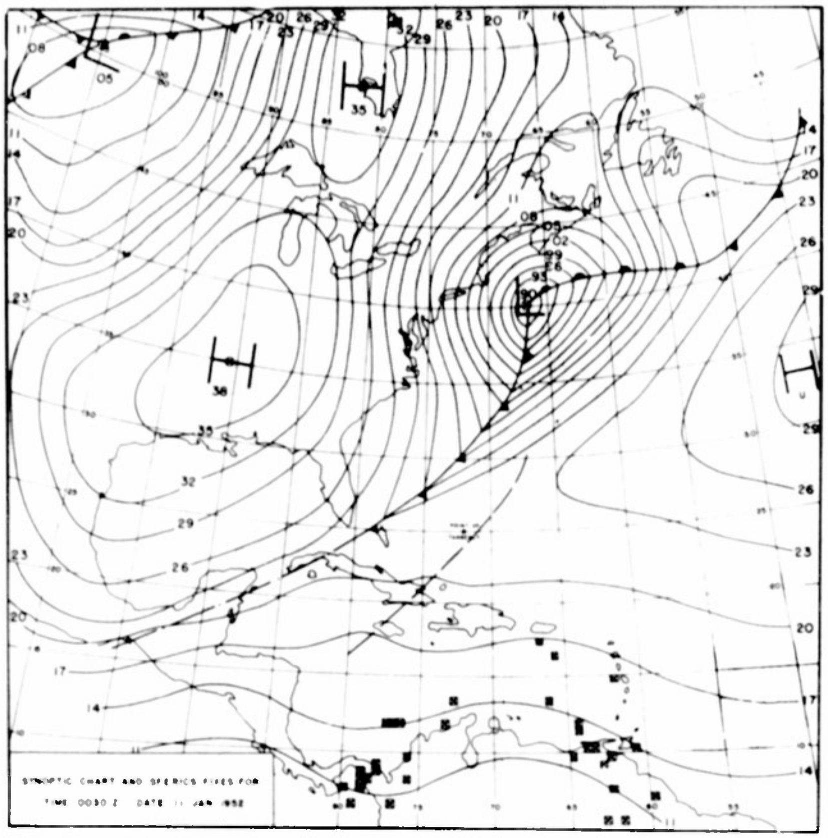

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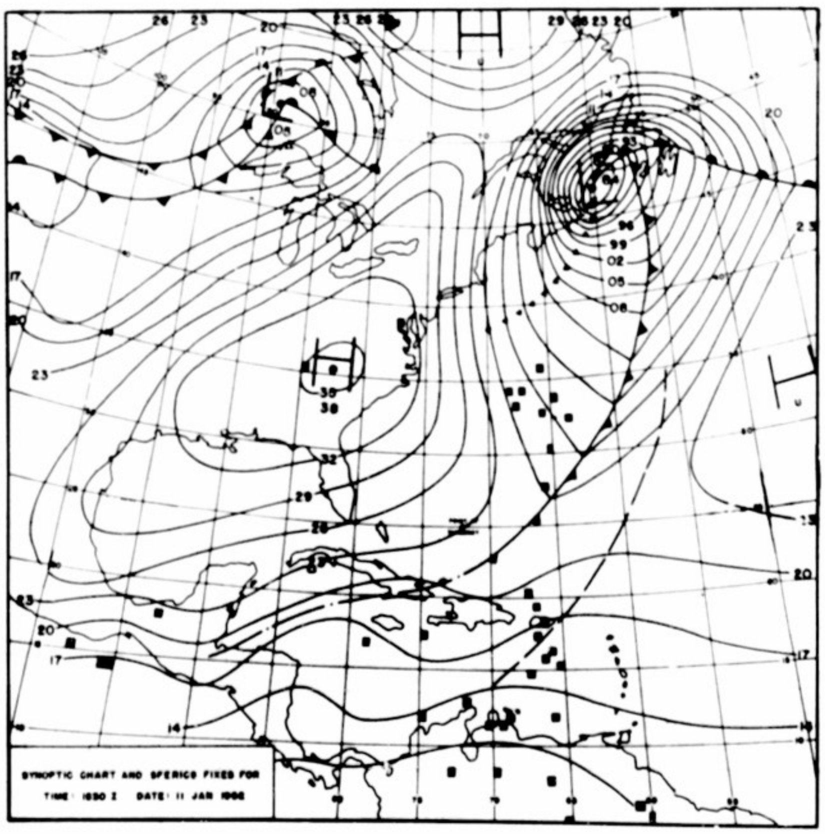

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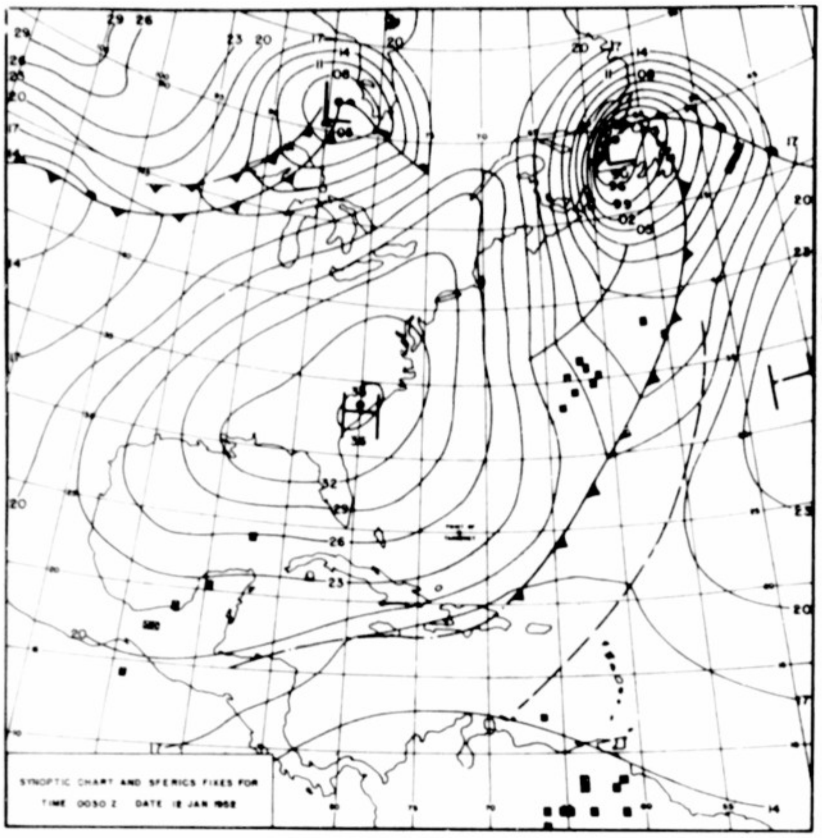

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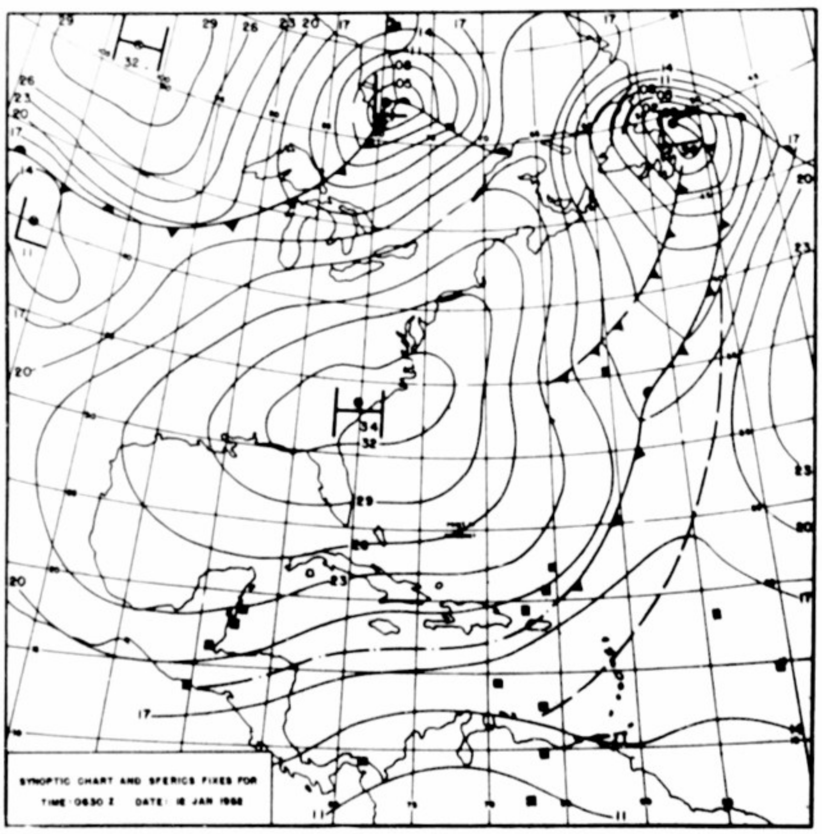

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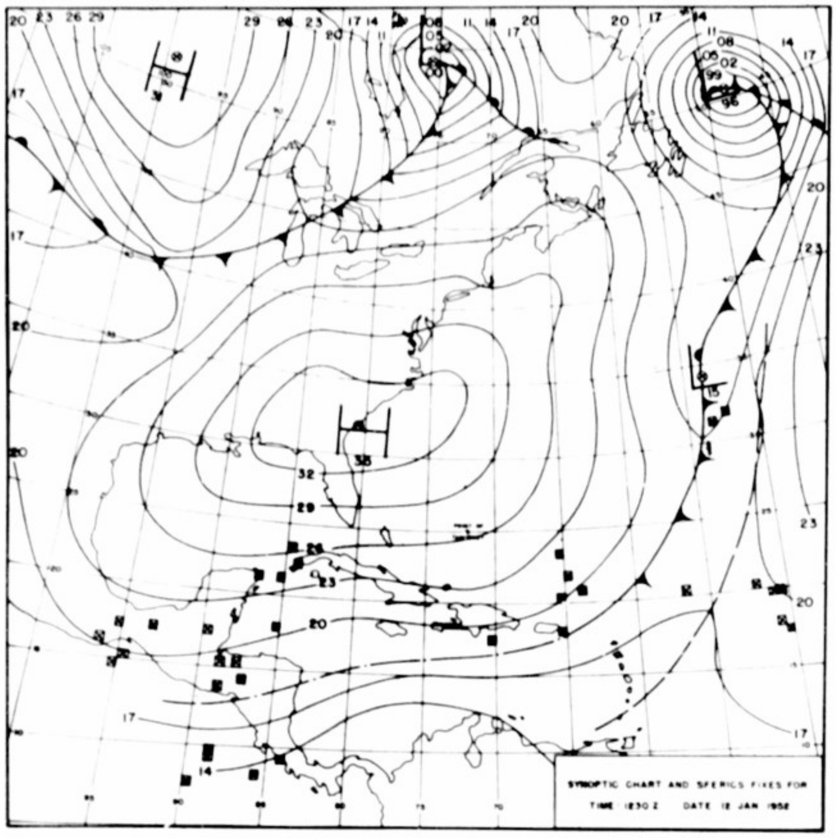

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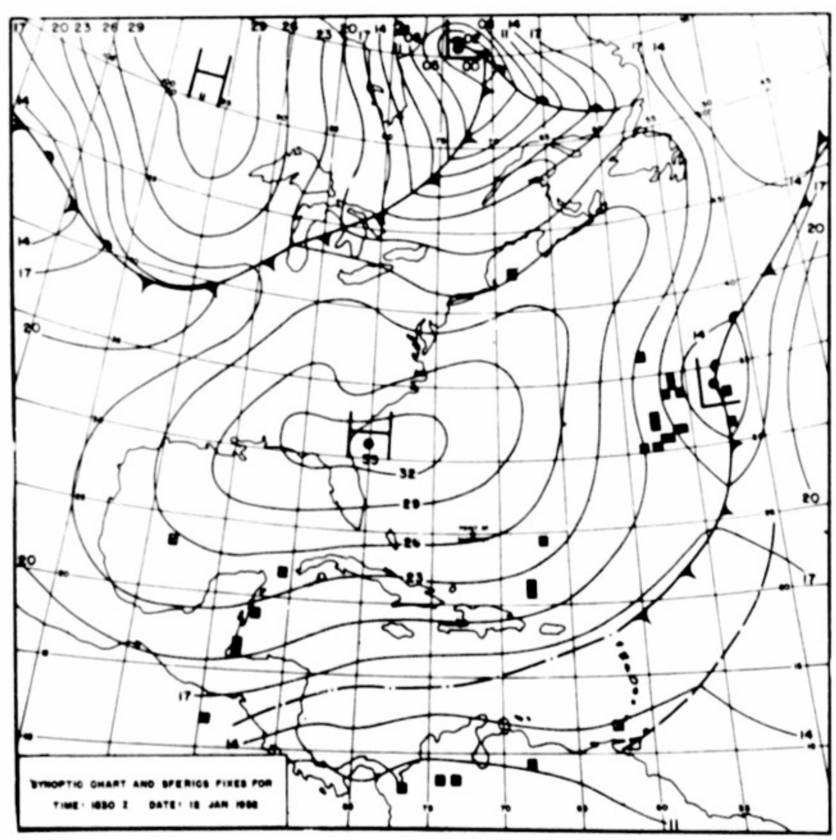

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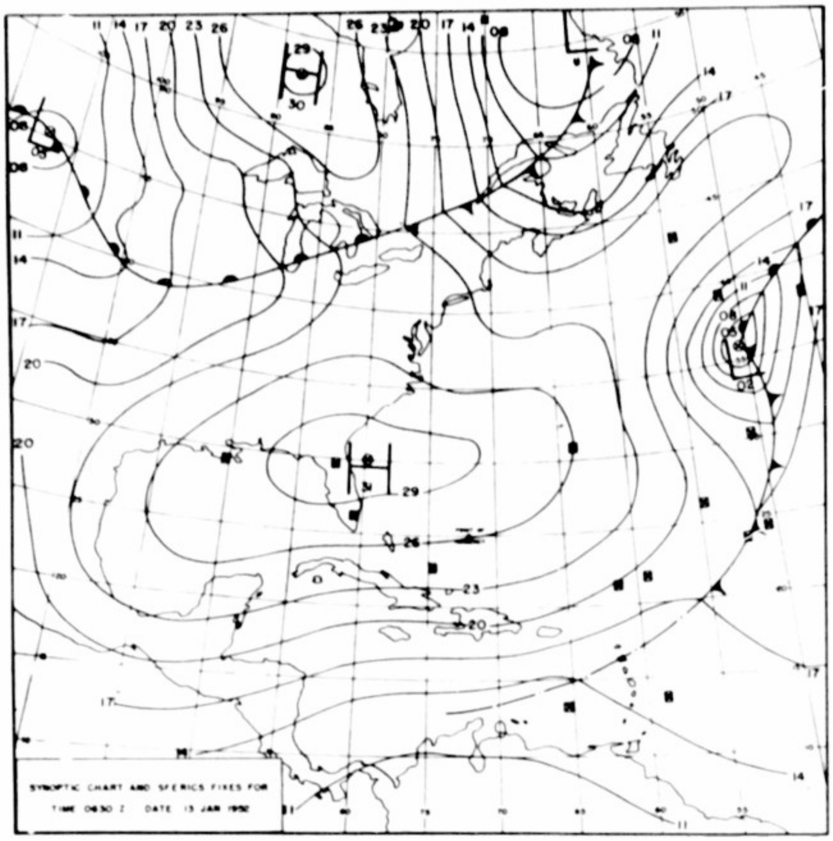

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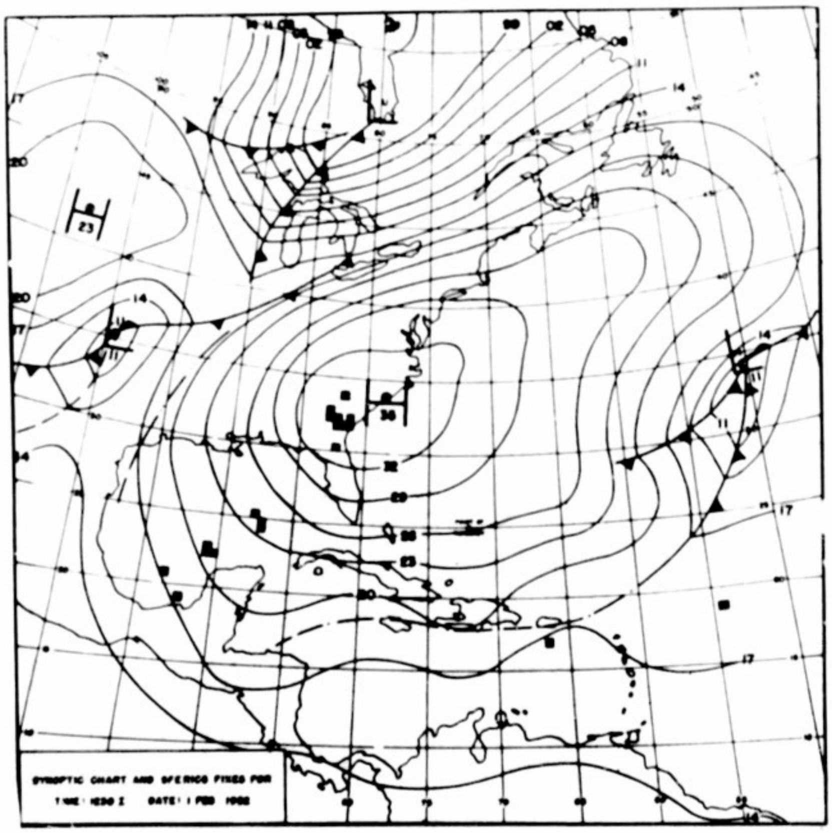

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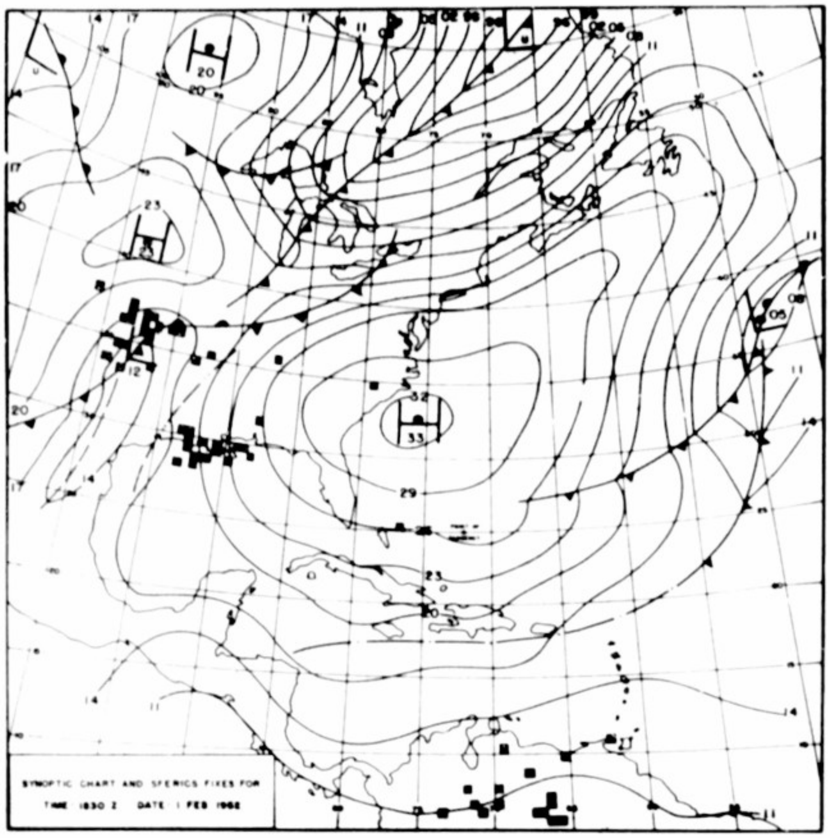

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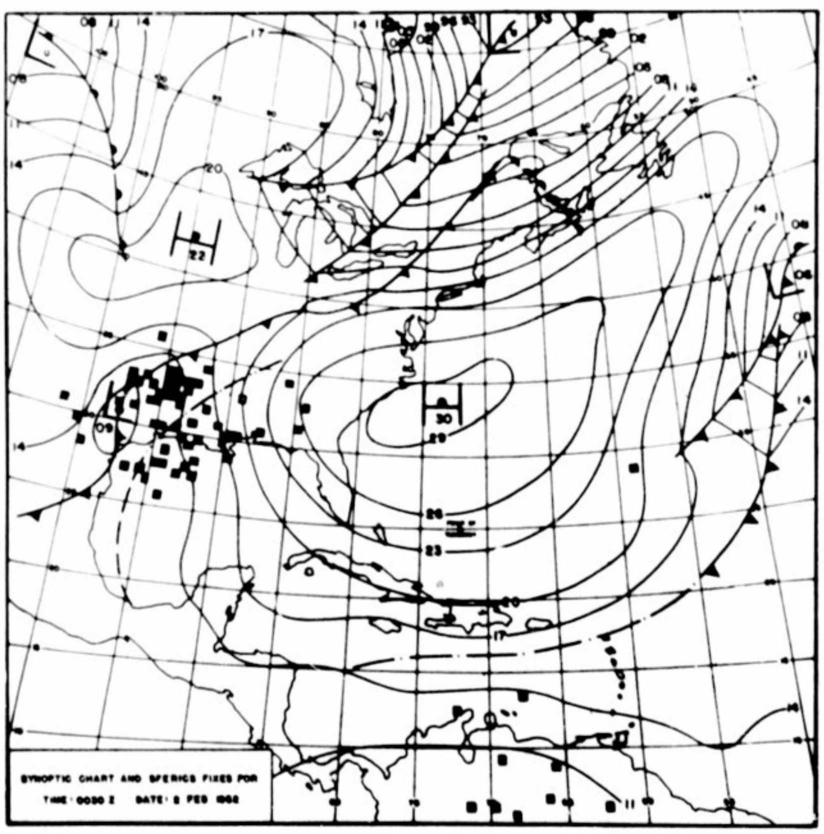

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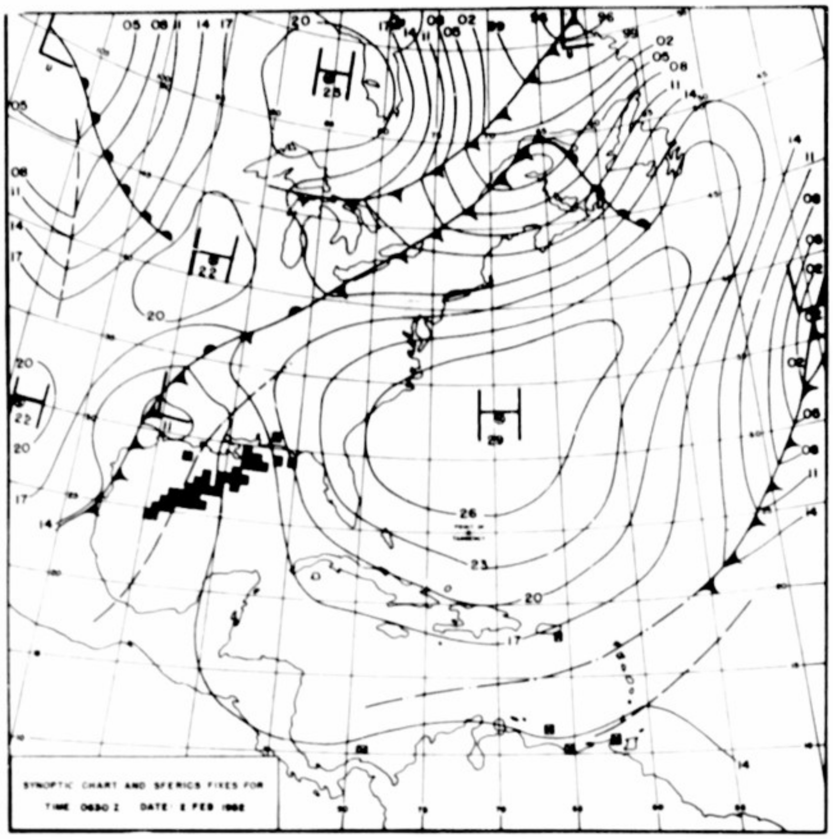

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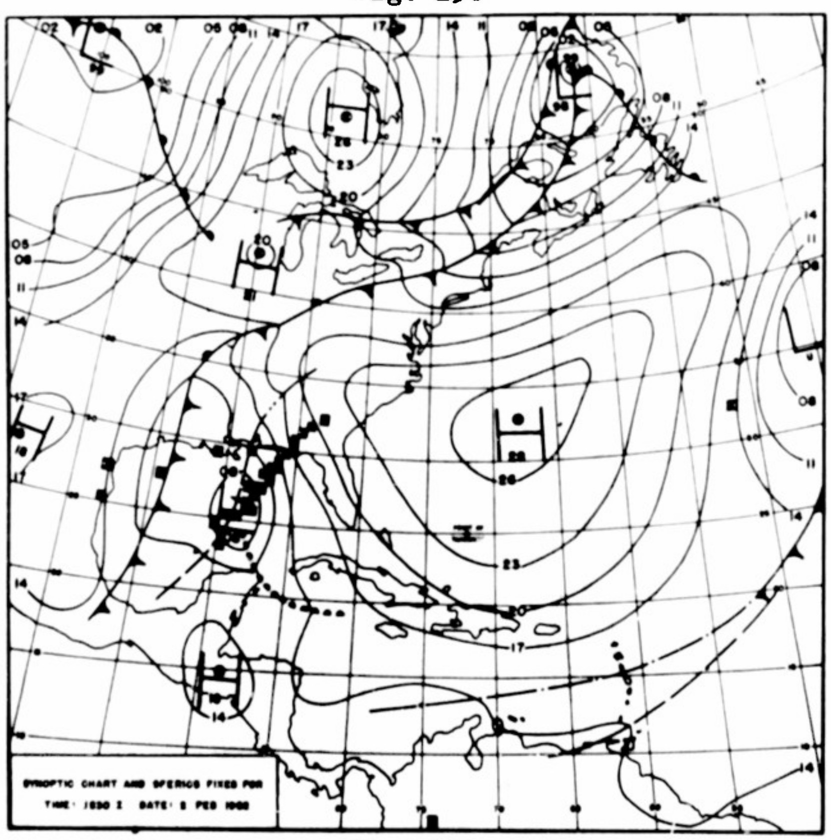

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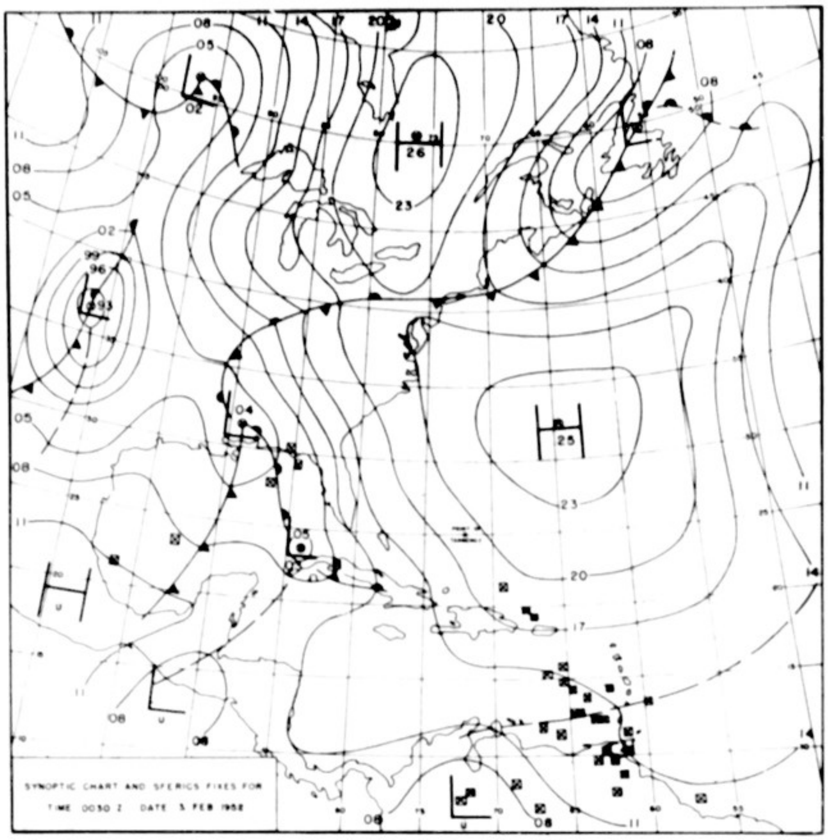

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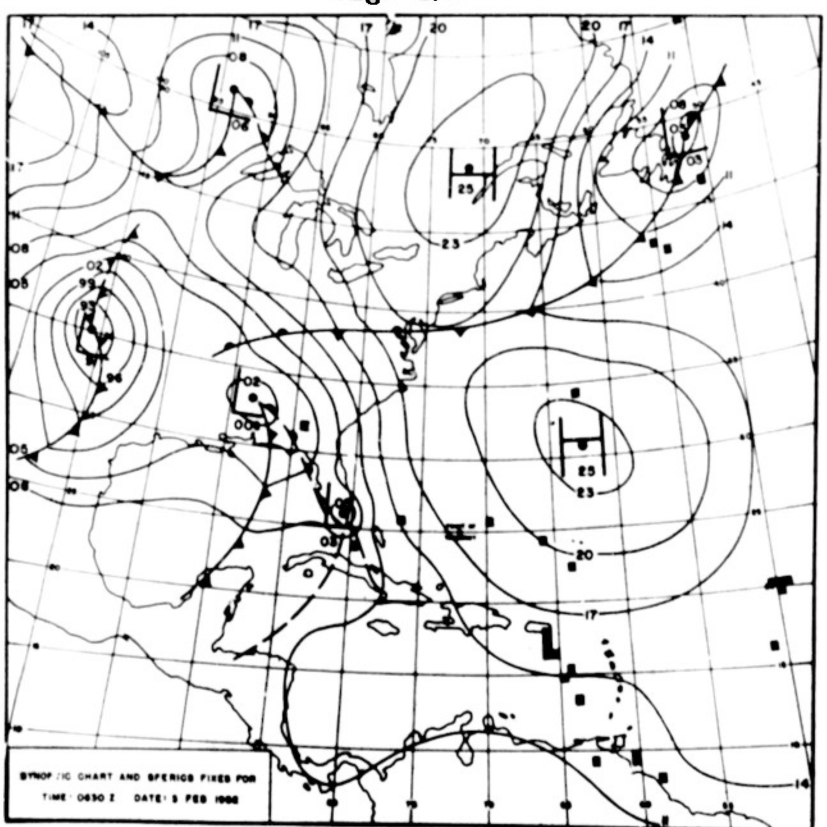

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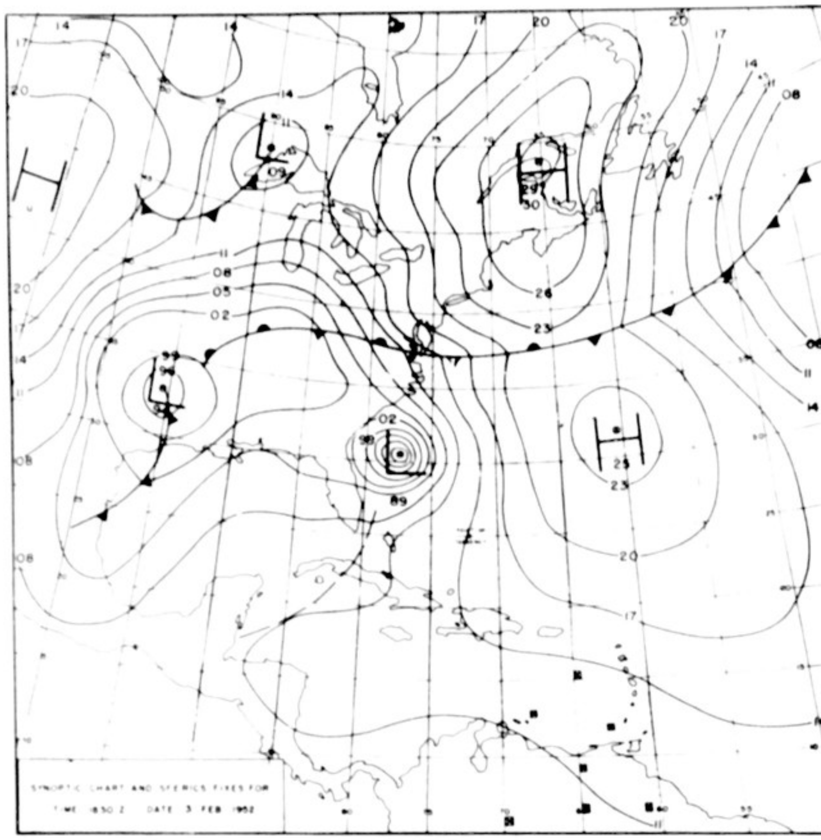

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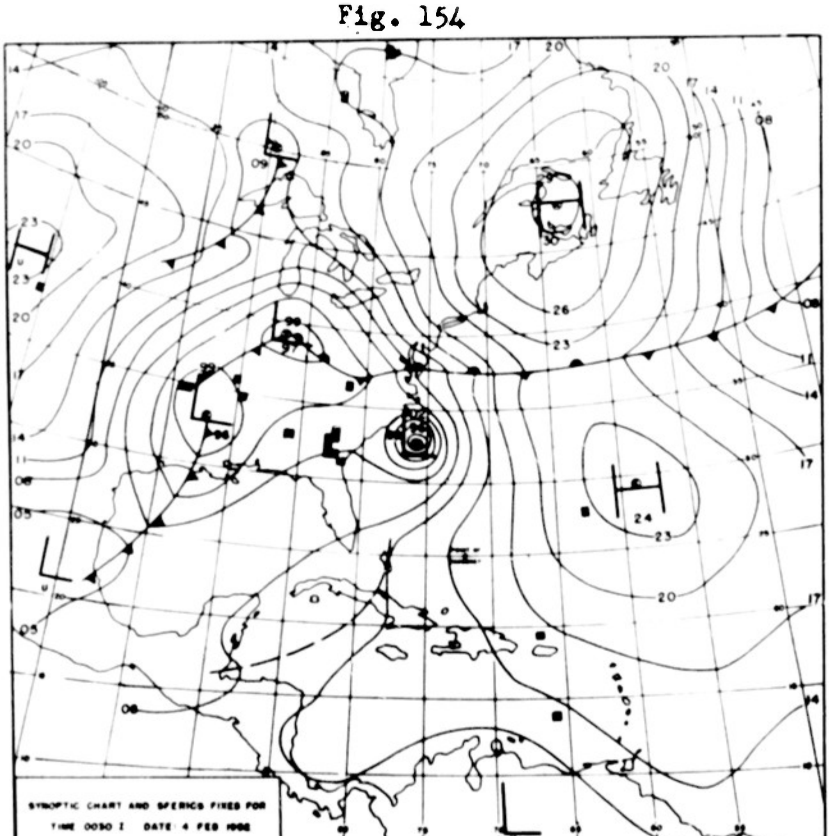

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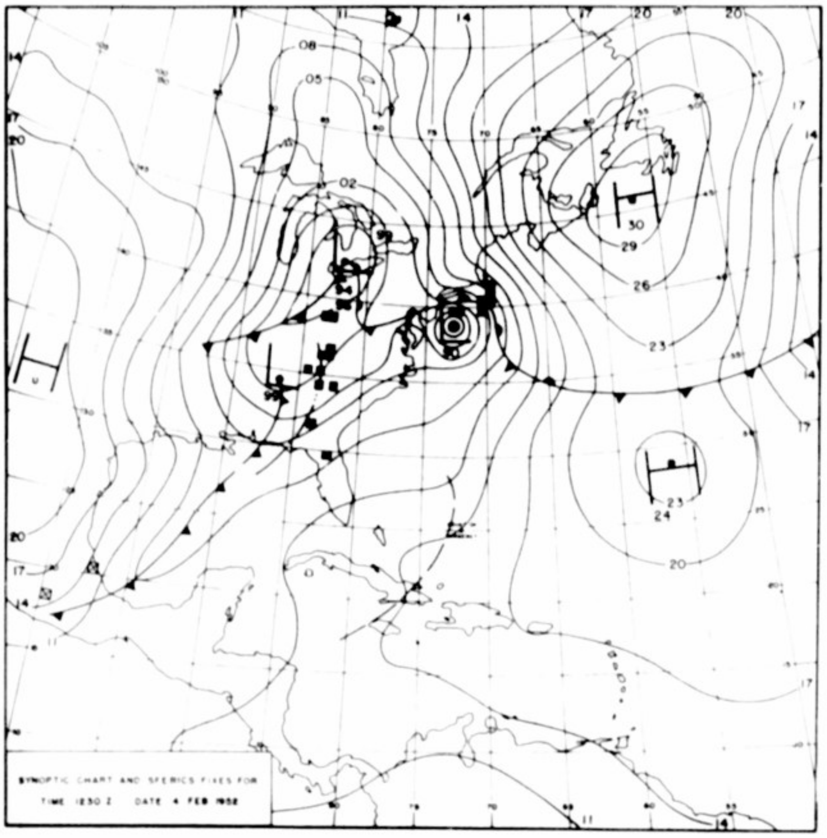

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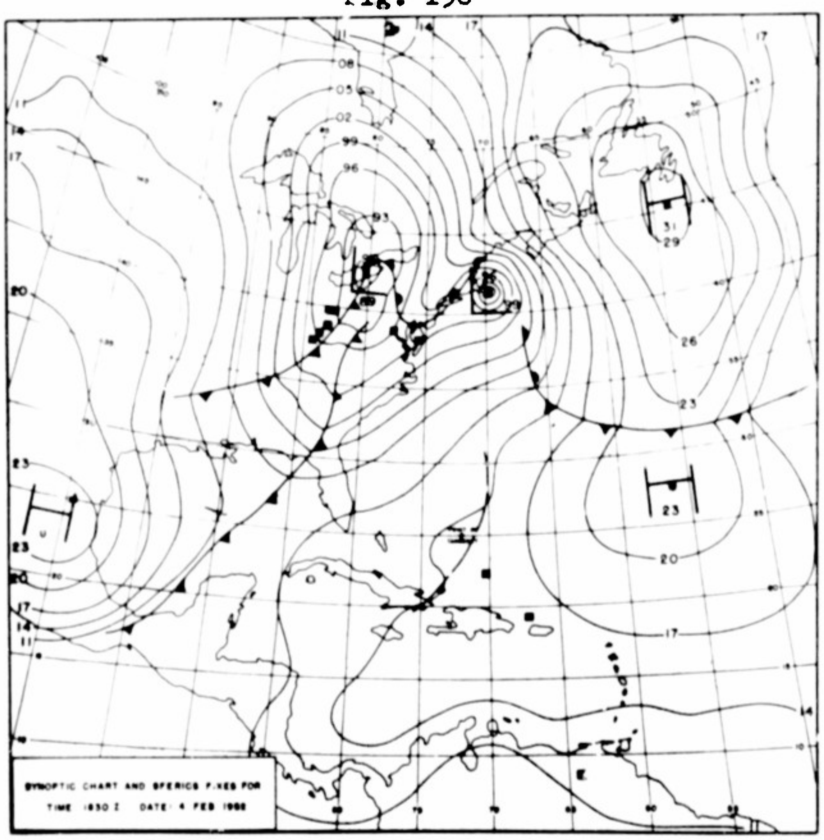

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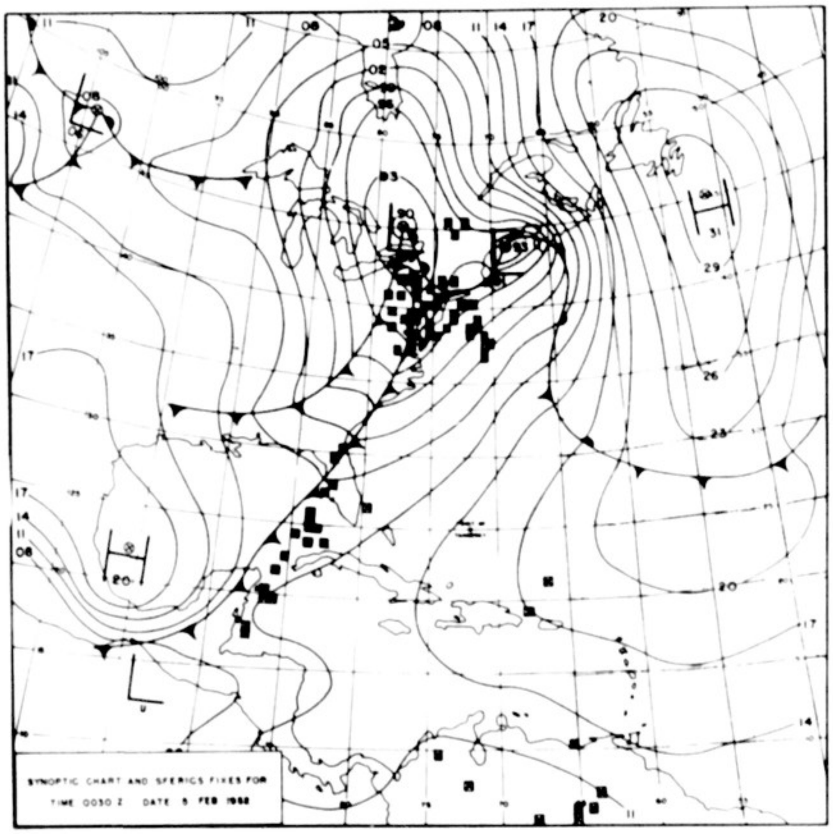

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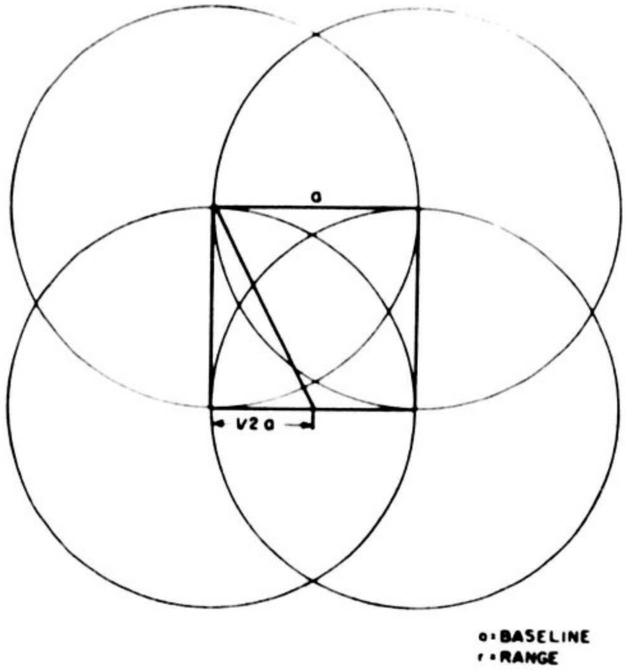

Fig. 159 Ideal Four-Station Net

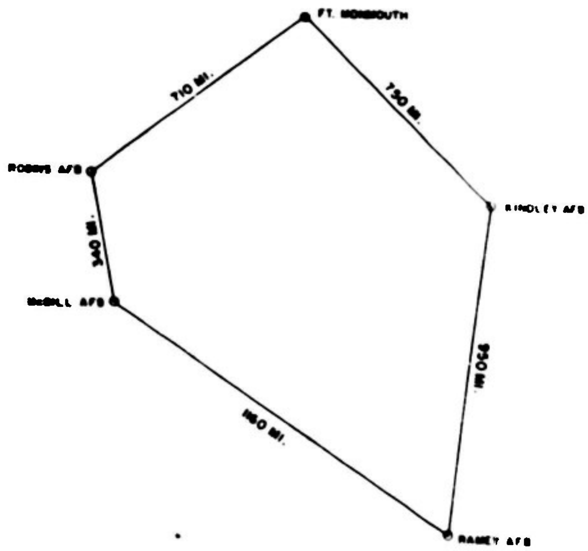

Fig. 160 Diagram Showing Relative
Location of Sferics Stations

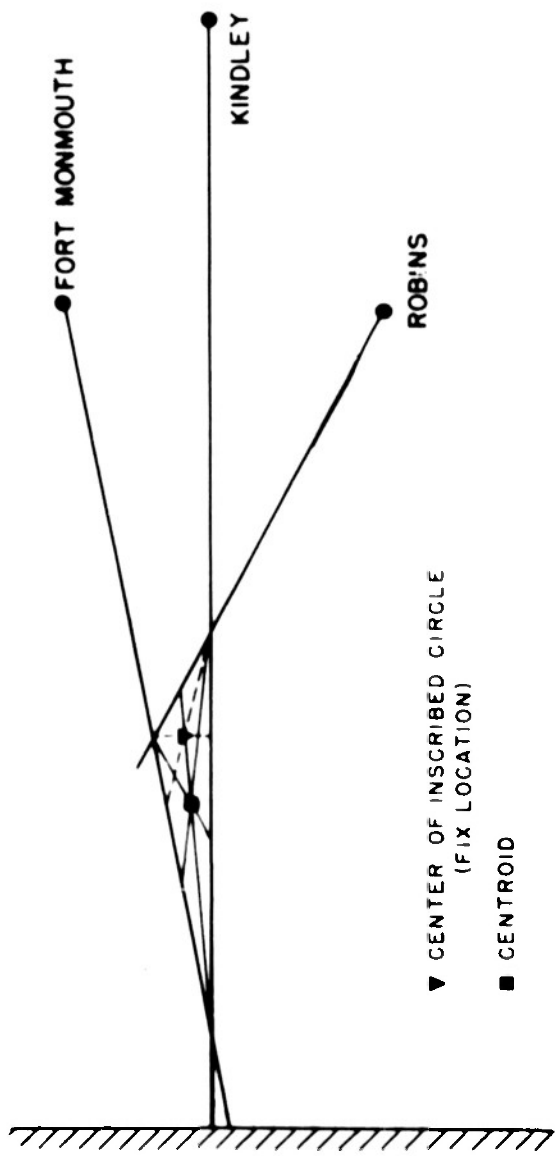

Fig. 161 Parallel Beam Uncertainty

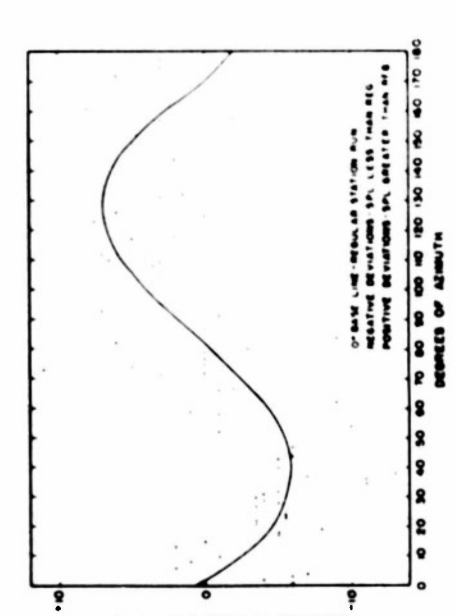

Fig. 162 Error Curve for Ramey Site 1

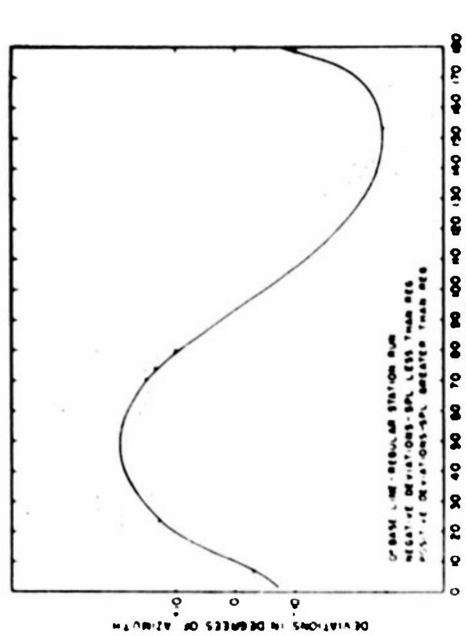

Fig. 163 Error Curve for Ramey Site 2

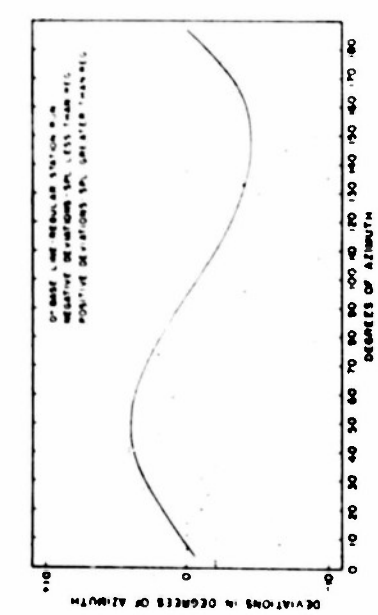

Fig. 164 Error Curve for Ramey Site 3

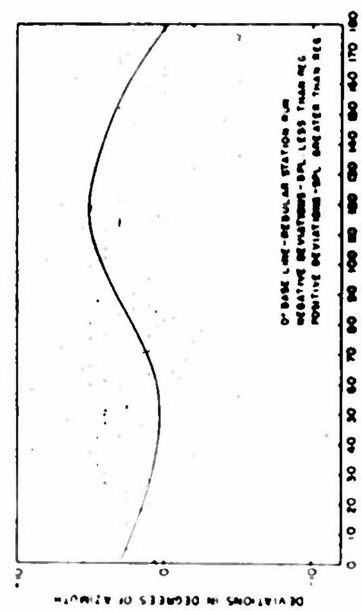

Fig. 165 Error Curve for Kindley

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